TECHNICAL MEMO:

FAR-FIELD SURVEYS OF SUSPENDED SEDIMENT PLUMES ASSOCIATED CUTTERHEAD DREDGING IN UPPER BAY

S-KVK-1 Contract Area (Kill Van Kull)

Prepared for

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1.0 INTRODUCTION

The resuspension of bottom sediments within aquatic habitats may be induced by a variety of events both natural and anthropogenic. Naturally occurring storms or tidal flows, for example, will influence suspended sediment concentrations within the water column although the scope, timing, duration and intensity of the resuspension may differ from that caused by human activities (Wilber & Clarke 2001). Information on the extent and nature of suspended sediment plumes generated by dredge activities, therefore, is critical to enhance the understanding of sediment transport processes and associated environmental concerns (Puckette 1998).

As part of U.S. Army Corps of Engineers New York District's (USACE-NYD) Harbor-wide Water Quality/Total Suspended Solids (WQ/TSS) Monitoring Program, a far-field WQ/TSS survey was conducted between 21 March 2011 and 25 March 2011 within the S-KVK-1 contract area of the Harbor Deepening Project (HDP) in the Constable Hook Reach of the Kill Van Kull in Upper Bay, New York (Figure 1). The objective of the far-field survey was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with cutterhead dredge operations. The methodologies employed for this survey were similar to those used previously to survey environmental or "closed" (i.e. with seals and flaps, as per contract specifications) clamshell bucket dredging of fine-grained sediment within the Arthur Kill (USACE 2007a), Newark Bay (USACE 2008 and USACE 2009) and Port Elizabeth Channel (USACE 2010).

Mobile surveys were conducted using a vessel-mounted Acoustic Doppler Current Profiler (ADCP) and consisted of parallel transects running perpendicular to the longitudinal axis of the suspended sediment plume. Transects were conducted adjacent to and down-current of the active cutterhead operation and were run such that the entire spatial extent of the plume's acoustic signature (i.e. the detectable signature above ambient backscatter) was recorded. To establish the calibration for the ADCP backscatter, water samples were collected to directly measure TSS concentration (via gravimetric analysis) and turbidity across the broadest possible range of tidal and concentration gradients.

1.1 Study Area and Dredge Operational Setup

The dredge contractor for this study was Great Lakes Dredge and Dock Company, LLC, operating the *Florida* configured with a 3,000 hp cutterhead dredge with an 11 foot diameter Esco 54D rotating cutter with a rotational speed of 26 rpm. Within the S-KVK-1 contract area the cutterhead dredge was employed to break apart the underlying Serpentinite bedrock. Once cut, the dredge's hydraulic suction pipeline was configured to move the broken rock from below the cutterhead to an adjacent area on the channel bottom through an installed downspout. The cut rock was then removed using the *New York*, which followed immediately behind the *Florida*, and was configured with an up to 24 cubic yard (CY)-sized mechanical excavator dredge.

Far-field WQ/TSS surveys were conducted between 21 March 2011 and 25 March 2011 in the vicinity of this dredging operation within Acceptance Area H of the S-KVK-1 Contract Area. For all surveys, the cutterhead was situated within the Constable Hook Reach of the Kill Van Kull between the Green "#3" and Red "#2" navigation buoys (Figure 1). This is a high volume vessel traffic area frequented by tugs and barges as well as large deep draft commercial vessels including container ships, car carriers, and is near the Staten Island Ferry St. George-Whitehall route.

2.0 METHODS

2.1 Hydrodynamic Survey

Hydrodynamic conditions within the Kill Van Kull Channel were assessed during both ebb and flood tides using a vessel-mounted Teledyne RD Instruments 1200-kHz Workhorse Monitor Series ADCP. The mobile transects were conducted perpendicular to the Kill Van Kull Channel.

ADCP data provided a characterization of prevailing hydrodynamic conditions within the Study Area. Raw data from the hydrodynamic surveys were processed and examined for evidence of stratified flows, tidal eddies, and other patterns that could influence plume dispersion. The observed hydrodynamic conditions were then cross-referenced against the preliminary currents data collected by NOAA Station n03020 at The Narrows (NOAA 2011) to place the survey within the context of the daily tidal cycle.

2.2 Survey Design of Mobile ADCP Transects

Suspended sediment plumes were also characterized using the ADCP. In the field, RD Instruments WinRiver software was used for the display of plume acoustic signatures and data recording. The ADCP operates by emitting acoustic pulses into the water column at set time intervals. Each group of pulses, referred to as an "ensemble," is vertically stratified into discrete, fixed-depth increments, or "bins." The number of bins and size of each bin is a configurable operation parameter of the instrument. In this study, 40 bins of 0.5-meter depth were used, for a maximum profile range of 20 meters. After the instrument emits a pulse, the ADCP then "listens" for the return of any sound (i.e. backscatter) that has been reflected from particles in the water column (in this case, a "particle" is any acoustic reflector, including sediment, plankton, fish, air bubbles etc.). Once the instrument receives the reflected signals, the WinRiver software can calculate the three-dimensional movement of particles in the water column and thus determine water velocity in each bin. When water samples are collected concurrently, suspended sediment concentration can be determined using additional software and analyses (see *Section 2.5 - ADCP Calibration* below). Similarly, navigation data (i.e. GPS positions)collected throughout the monitoring period by the cutterhead contractor were integrated during post-processing of the ADCP data to determine the distance each transect was from the source. To cover a range of tidal conditions, ADCP backscatter data were collected during various stages of ebb and flood tides during the survey period.

Prior to initiating the mobile plume surveys, circular transects using the ADCP were conducted around the actively operating cutterhead to assess the location and acoustic strength of the plume. Subsequent ADCP transects were generally oriented in a direction perpendicular to the channel and extended down-current until the plume's acoustic signatures could no longer be detected against background conditions. Background conditions on the days of the surveys were determined by conducting ambient transects up-current of the plume and outside the active cutting area. Individual transect length was generally determined by bathymetry at the site, but always with the objective of extending beyond the detectable boundaries of the plume. The number, and consequently the spacing, of cross-plume transects were maximized within each designated tidal phase in order to provide complete spatial coverage of the detectable plumes and optimal resolution of internal plume structure.

Results for the mobile ADCP plume transects are presented graphically in three ways:

- **Vertical Profile Plots** – Vertical cross-section profiles representing individual transects are examined in detail for TSS concentration gradient structure of the plume at fixed distances from the source.

- **Plan View Plots** – TSS concentrations are presented as composite horizontal "slices" through the plume signature at two meter depth increments.

- **Three-dimensional Plot Depiction** – Selected transects are plotted three dimensionally and superimposed on the existing bathymetry to show the spatial extent of the plume within the channel (note: the depth (Z) axis is exaggerated to show detail better since the X,Y spatial extents are much larger then the Z extents). Channel bathymetry was generated using NOAA sounding data.

For all figures, unless otherwise noted, estimates of TSS concentrations above ambient concentration are assumed to be associated with cutterhead activities.

It is important to note that the ADCP cannot simultaneously receive and emit an acoustic pulse. Thus, when emitting a pulse, the ADCP cannot obtain data from immediately in front of its transducers (in addition to the water above the immersion depth of the instrument itself). This "blanking distance" is a user-defined parameter with limitations imposed by the operating frequency of the ADCP. For the 1200-kHz ADCP used in this survey, the blanking distance is approximately 0.5 meters (i.e. one bin depth).

In addition, acoustic "echoes" reflected from the seabed may interfere with the ADCP signal. The ADCP emits most of its acoustic energy in a very narrowly confined beam; however, a small amount of energy is emitted at angles far greater than that of the main lobe. These "side lobes", despite their low power, can contaminate the echo from the main lobe, typically in the area directly above the seabed. The net effect of this side lobe interference is to show erroneously high backscatter from the near-seabed areas. This effect is exacerbated in vessel-mounted surveys when the seabed elevation changes rapidly (e.g. during the transition from the shallows to the channel areas or vice-versa). In general, the side lobe distance above the seafloor is equal to approximately 6% (i.e. cosine of the 20° beam angle) of the water depth at that point.

2.3 Design of Fixed Station Turbidity Survey

In addition to the mobile ADCP surveys, turbidity measurements were recorded at fixed locations and at various water depths using Campbell Scientific, Inc.'s (formerly D&A Instrument Company) OBS-3A turbidity sensors tethered to a taut line and anchored at predetermined depths using a fixed anchor and buoy array. Optical backscatter sensors (OBS) project a beam of near-infrared light into the water, and measure the amount of light reflected back from suspended particles. The OBS units used in this survey were pre-calibrated by the manufacturer and programmed to measure turbidities in the 0-1,000 Nephelometric Turbidity Unit (NTU) range. The OBS units deployed during the fixed station survey were configured to output depth (mean + standard deviation, in meters), turbidity (mean + standard deviation, in NTU), temperature (°C), salinity (ppt), conductivity (mS/cm) and battery level (V). Readings were logged internally every 10 seconds at a rate of 25 samples per second for duration of 5 seconds. That is, every 10 seconds the OBS recorded 125 samples (25 samples/sec x 5 sec). All internally recorded data were retrieved from the units at the end of the survey.

2.4 Water Sample Collection

During the far-field survey, water samples were collected to measure and calibrate TSS concentrations (mg/L) and turbidity (NTU) throughout the water column. The water samples were collected from the survey vessel using a Sea-Bird Electronics SBE32C Compact Carousel Water Sampler equipped with six 1.7L Nisken sample bottles. A Campbell Scientific, Inc. OBS-3A optical backscatter sensor was also mounted to the Carousel Sampler and hardwired directly to an onboard laptop. The OBS unit provided depth, temperature, salinity, and turbidity values of the entire water profile. The Carousel Sampler was also hardwired to an onboard laptop and featured a magnetically-actuated lanyard release system used to remotely "fire" the sample bottles. A custom application recorded the exact time that each bottle fired to the nearest second.

All the water samples collected in the field were processed in the laboratory by Test America Laboratories, Inc. for optical turbidity (Method SM 2130-B) and for the gravimetric analysis of TSS concentration (Method SM 2540-D). The laboratory results were then used to provide a robust calibration data set to convert the raw ADCP backscatter measurements to estimates of TSS concentration using the Sediview methodology and software as further described below.

2.5 ADCP Calibration

Following the field data collection effort, the raw acoustic backscatter measurements collected by the ADCP were converted to estimates of suspended sediment concentration using Sediview Software provided by Dredging Research, Ltd. The Sediview Method (Land and Bray 2000) derives estimates of suspended solids concentration in each ADCP data bin by converting relative backscatter intensity to TSS concentration. This process requires collecting a calibration data set consisting of discrete water samples and concurrently recorded ADCP acoustic backscatter data. The degree of confidence that can be placed in the estimates of TSS is proportional to the strength of the calibration data set. The quality of the calibration is in turn dependent on the collection of adequate water samples to represent sediments in suspension at all depths in the water column and across the entire gradient of concentrations occurring in ambient as well as plume conditions.

Samples were collected at known locations within the water column, so that individual gravimetric samples could be directly compared with acoustic estimates of TSS concentration for a “bin” of water as close to the water sample as possible. Following the Sediview calibration, the results were then applied to all of the ADCP files recorded during each of the far-field surveys, resulting in an ADCP-derived estimate of TSS concentration for each recorded ADCP bin for an individual far-field survey. Note, because of the continuously changing ambient conditions present in estuaries, it is important to collect water samples frequently and it is often necessary to perform multiple calibrations specific to the time period where the ADCP data were collected. It is also important to collect enough samples to constitute a robust sample size as it is occasionally necessary for some samples to be excluded. For example, samples may exhibit excessively high TSS based on the disturbance of bottom sediments by the Carousel Sampler (i.e. the Carousel apparatus impacts the sea floor) or if the ADCP backscatter exhibited signs of air bubble contamination (e.g. air bubbles will show as extremely high backscatter/TSS estimates but the corresponding water sample for that time/position is relatively low) or interference (e.g. the ADCP beam(s) reflect off the carousel sampler apparatus itself, causing an erroneously high reading).

2.6 Sediment Sample Collection

Sediment samples were collected once per day from the sediment bed in the vicinity of the cutterhead using a ponar grab. These samples were analyzed in the laboratory by Test

America Laboratories, Inc. for sediment grain size distribution (ASTM D-422 Method), density (ASTM D-2937 Method) and Atterberg Limits (ASTM D-4318 Method).

3.0 RESULTS

3.1 Hydrodynamic Survey

General hydrodynamic conditions within the Kill Van Kull and its immediate vicinity were assessed during both ebb (24 March) and flood tides (25 March). Transects were conducted approximately perpendicular to the Kill Van Kull Channel. Additionally, the specific hydrodynamic conditions during each mobile ADCP survey (see below) were also recorded to aid in the interpretation, and place the corresponding TSS data in a hydrodynamic context. The results of the hydrodynamic surveys are presented on Figures 2a-2c.

For comparison purposes, the NOAA Preliminary Currents Data recorded from Station n03020 at The Narrows (NOAA 2011) for the respective survey day is also shown on Figures 2a-c. The NOAA data show the Near Surface water speed (in cm/s; red line) and direction (in degrees from True North; green crosses) and is useful to place a particular survey within the daily tide cycle.

3.1.1 21 March 2011 (Flood Tide)

Field surveys commenced at 09:45 on 21 March 2011, but due to rough sea conditions (winds SW 15-20 mph, and waves of 2-3 feet) over 10% of the ADCP collected showed signs of corruption (excessive pitch and roll prevents the collection of quality ADCP data as the internal vertical gyro and inclinometer cannot compensate quickly enough). Further, for safety reasons, the wind and wave conditions made deploying the carousel sampler to collect water samples untenable. As a result, no useable data were collected this day.

3.1.2 22 March 2011

Similar to the previous day, all survey activities for 22 March were cancelled due to inclement sea conditions and excessive winds.

3.1.3 23 March 201 (Flood Tide)

Figure 2a presents the results of the hydrodynamic survey conducted on 23 March 2011 during the middle of a flood tide from approximately 09:30 to 12:12. During the survey, depth averaged current velocities within the area ranged between 0 cm/s and up to approximately 40 cm/s (Figure 2a). Within the majority of the Kill Van Kull Channel, currents generally flowed in a west-northwest direction; however towards the southern portion of the survey area (near the Staten Island shore) the direction of the current swept around in the opposite direction, but at low velocities (<30 cm/s).

3.1.4 24 March 2011 (Ebb Tide)

Figure 2b presents the results of the hydrodynamic survey conducted on 24 March 2011 during the beginning portion of an ebb tide from approximately 13:35 to 15:07. During the survey, depth averaged current velocities within the area ranged between 20 cm/s and up to approximately 60 cm/s (Figure 2b), excluding an area where excessive prop wash from a passing tug boat caused abnormally high velocities. Current direction essentially followed the curvature of the Staten Island shoreline with currents in the western portion of the survey flowing towards the east and the currents in the eastern part of the survey area flowing in a southeast direction.

3.1.5 25 March 2011 (Flood Tide)

Figure 2c presents the results of the hydrodynamic survey conducted on 25 March 2011 during the end portion of an ebb tide and beginning portion of a flood tide from approximately 09:11 to 11:49. During the survey, depth averaged current velocities within the area ranged between 20 cm/s and up to approximately 60 cm/s (Figure 2c). Current direction essentially followed the curvature of the Staten Island shoreline with currents in the eastern portion of the survey flowing towards the northwest and the currents in the western part of the survey area flowing toward the west.

3.2 Ambient conditions

It is important to consider that no single TSS measurement adequately represents ambient conditions; instead a range of samples variable with regard to depth and tidal conditions is a better representation of the dynamic nature of suspended sediment concentrations in a tidal estuary. A total of 36 ambient water samples were collected at various depths on 24-25 March 2011, and later analyzed in the laboratory for TSS and turbidity (Table 1).

Ambient turbidity values ranged from 5 to 20 NTU, and the corresponding TSS values ranging between 18.5 to 70.5 mg/L. However, for the purposes of delineating the margins of a sediment plume, it is necessary to determine a single critical TSS concentration, below which are ambient conditions and above which are plume conditions. Because of the naturally heterogeneous distribution of suspended sediment, ambient conditions are often associated with a large range of TSS concentrations and the distribution of these values is rarely symmetric. As a result, the average ambient TSS measured will often underestimate the ambient condition and thus using a percentile approach as a measure of central tendency is more applicable. Choice of which percentile to use is largely a matter of which one most clearly demarcates the plume from the background condition (i.e. removes the natural "noise" of the ambient condition), but typically it ranges from the 50^{th} percentile (median) to 95^{th} percentile. For this study, the 85^{th} percentile of 65 mg/L was used as the TSS critical value. Hence, all acoustically estimated TSS concentrations greater than 65 mg/L are herein considered above background and attributable to the cutterhead-induced plume unless otherwise noted, e.g., clearly attributable to air entrainment, vessel prop wash, or from other sources of resuspension such as tug and ship plumes (see ADCP calibration methods, Section 2.5, for further information).

3.3 Mobile ADCP Surveys

3.3.1 23 March 2011 (Flood Tide)

The 23 March 2011 mobile ADCP plume characterization was completed during the peak of a flood tide from approximately 09:30 to 12:12 (Figure 3a-u). The survey consisted of three ambient transects (Figures 3a through 3c), three circle transects (Figures 3d through 3f), and one set of down-current transects (Figures 3g through 3u). A summary of each of the graphically represented transects is presented in Table 2.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 4a through 4h. For this survey, the cutterhead was located approximately 237 meters north-northeast of the green "3" navigation buoy. Ambient transects were conducted east of the cutterhead while down-current transects were west of the cutterhead and oriented perpendicular to the channel. Figure 5 provides a three-dimensional depiction of average TSS values for selected representative transects superimposed on existing channel bathymetry. Bathymetry was computed from soundings reported on NOAA nautical charts.

Up-current ambient conditions presented in Figures 3a through 3c showed TSS concentrations between 0 and 80 mg/L throughout most of the water column, which is consistent with the results of the gravimetric water samples collected. Estimated TSS concentration signatures above ambient (65 mg/L) associated with the cutterhead operation were primarily limited to within the first 374 meters down-current of the cutterhead (Transects T01 – T07). In these transects, a clearly defined plume is visible in the bottom quarter of the water column, with peak concentrations of 200 mg/L near the seabed within 189 meters of the source (Transect T02). Plume width varies from approximately 60-150 meters at various locations, being more narrowly confined closer to the cutterhead and expanding laterally as the distance from the cutterhead increases. Since many of the transects extend into shallower water, some sidelobe reflectivity was observed on the slopes.

In Transects T12 – T15 (601-811 meters from the cutterhead, respectively) another plume can be seen that extends throughout the water column. This plume was likely caused by several large ships and tugs that passed for 30 minutes between the T11 and T12 transects (see Table 2), and are thus not related to the plume generated from the cutterhead. Some of this traffic was associated with the fuel docks at Constable Hook, but due to security restrictions around these docks, the field crew were unable to extend the transects any closer to the fuel docks at Constable Hook.

3.4 Fixed Station Turbidity Survey

One fixed station turbidity survey was conducted on 24 March during a flood tide. A total of three fixed arrays were deployed (one ambient and two down-current of the plume). The ambient array consisted of one OBS unit tethered at mid-depth while each of the down-current arrays consisted of two OBS units each tethered at mid-depth and near bottom based on water depth. It is assumed for purposes of this study that the ambient suspended sediment concentration is homogenously distributed throughout the water column. Each of the fixed arrays (both ambient and down-current) was located within the vicinity of the active cutterhead operation. The down-current arrays were positioned at the edge of the channel at various locations with the objective to examine turbidity structure within the plume at varying distances from the dredge.

3.4.1 Flood Tide (24 March 2011)

A fixed station turbidity survey was conducted on 24 March during a flood tide. Figure 6 shows the location of the two down-current arrays and the one up-current array with respect to the cutterhead position. The down-current arrays were located 405 and 530 meters away from the cutterhead, respectively. The up-current array was located 400 meters from the cutterhead. The fixed OBS arrays were placed closer to the shoal as to avoid any potential hazards to navigation Figure 7 plots the recorded turbidity values (NTU) from the mid-depth (black line), and bottom (red line) OBS units. Ambient turbidity is plotted as a blue line and superimposed on both of the down-current plots for comparison.

Both down-current arrays showed that the mid-depth and bottom turbidities were very similar to the ambient mid-depth turbidity throughout most of the survey (Figure 7). There are two turbidity spikes of approximately 200 and 600 NTU near the bottom in the farthest array between 12:25 – 12:40. This time coincides with the time the field crew observed that all cutting had stopped and the cutterhead was fully out of the water. While it is possible that the removal of the cutterhead caused a spike in the bottom turbidities, it is unlikely this is the cause for a variety of reasons including: the distance and direction from the source (the flood TSS survey taken the previous day shows the plumes maximum down-current distance was approximately 374 meters and it generally traveled towards the Constable Hook Reach); the same turbidity spike was not seen on the closer array; the spike could have been generated from another source (passing ship or tug etc.). Several other small (<100 NTU) turbidity spikes along the bottom are also seen in Figure 7, however these are also likely due to other factors (turbidity will naturally be higher and fluctuate along the bottom).

3.5 Laboratory Analysis of Water Samples

A total of 108 water samples were collected in the project area during the week of 21 March 2011. The laboratory results of the optical turbidity and the gravimetric analysis of TSS concentration of those 108 samples are presented in Table 1. To accommodate the requirement for calibration of the ADCP backscatter, samples were taken from locations to represent the broadest possible concentration gradient from ambient to the highest TSS concentrations that could be safely collected in the area of the active cutterhead operation.

In this study, the TSS concentrations of the 108 water samples ranged from 18.5 to 169 mg/L and turbidity ranged from 4 to 62 NTU. However, care must be exercised when interpreting turbidity results as turbidity measurements of the same sample from different instruments and methods will often yield different results. That is, turbidity measured with an OBS will not necessarily generate the same results as turbidity measured in lab (Lewis et al. 2007, Ziegler 2002).

Figure 8a plots the paired gravimetric measurements and ADCP acoustic estimates of TSS arranged in concentration versus time order for the water samples used in the Sediview calibration for the 23 March 2011 flood tide survey. Note that some of the 108 water samples collected were excluded if they exhibited clear signs of air bubble contamination, interference with the water sampler apparatus, or contact with the sea bottom (see ADCP calibration methods described in section 2.5). Overall, there was a strong agreement (R^2 = 0.77) between the acoustic estimates of TSS concentration and the gravimetric measurements (Figure 8b).

3.6 Sediment Samples

A total of 6 sediment samples were collected during the week of 21 March 2011. The laboratory results of these sediment collections for grain size distribution, density and Atterberg Limits are presented in Table 3. Sediment samples collected on 23 March were comprised mostly of fine sand and a little silt, with fine sand comprising between 69.8% and 72.7% of each sample collected. Sediment samples collected on 24 March were also mostly comprised of fine sand (40.2% - 45.6%), but with the remainder being medium sand (30.4% - 34.8%) instead of silt. The in-place density of the sediment samples ranged between 1.26 and 1.52 g/cc (Table 3).

4.0 DISCUSSION

During the course of normal dredging operations, some sediment is resuspended into the water column. In many cases, this suspended sediment is evident as a visible turbidity plume within the immediate vicinity of the dredge operation. Because suspended sediment plumes are dynamic rather than static phenomena and because they vary over large areas in short periods of time, particularly when driven by tidal forces, characterizing plumes can present a difficult challenge. Data collected at arbitrarily determined points in time at fixed locations are inadequate to assess dredge plume structure. However, advanced acoustic technologies offer advantages in capturing data at appropriate spatial and temporal scales to allow more accurate interpretation of plume dynamics (Tubman & Corson 2000).

As part of USACE-NYD Harbor-wide Water Quality/Total Suspended Solids (WQ/TSS) Monitoring Program, a far-field WQ/TSS survey was conducted between 21 March 2011 and 25 March 2011 within the S-KVK-1 contract area in the Constable Hook Reach of the Kill Van Kull in Upper Bay, New York (Figure 1). The objective of the far-field survey was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with cutterhead dredge operations. The methodologies employed for this survey were similar to those used previously to survey environmental or "closed" (i.e. with seals and flaps, as per contract specifications) clamshell bucket dredging of fine-grained sediment within the Arthur Kill (USACE 2007a), Newark Bay (USACE 2008 and USACE 2009) and Port Elizabeth Channel (USACE 2010). However, direct comparisons between studies are inexact due to the varying hydrodynamic conditions, sediment types within the different study areas and different dredge types.

The cutterhead dredge features rotating blades designed to directly loosen material efficiently to assist in the mechanical excavation of consolidated material (in this study, Serpentinite bedrock from the Kill Van Kull). Previous studies have shown that the mechanical mixing by the rotating cutterhead can be a factor in sediment resuspension at the point of dredging for this type of dredge but that sediment resuspension can be minimized through proper dredge design and operation (Havis 1988), which appeared to be the case during this field survey. During typical cutterhead operations, a hydraulic suction pipeline is used to directly remove the loosened material from the area of excavation. In this study, the cut rock was temporally relocated to an adjacent area on the channel bottom through an installed downspout before final removal using a mechanical excavator dredge[1].

Havis (1988) reported that sediment resuspension from cutterhead dredges is chiefly in the lower portion of the water column and that plume TSS concentrations measured during field studies of a cutterhead dredge operating in Calumet Harbor, Illinois did not exceed 200 mg/L. Although existing hydrodynamic and sediment conditions were

[1] Note that the complete operation using a cutterhead dredge involves the cutting of material and then the use of hydraulics to bring the material through the cutterhead to be removed. NYD did not request approval from the states to use hydraulics to bring material through the cutterhead to be removed. An intermediate step of using hydraulics to move cut material from the cutting face to be placed in a nearby area on the channel bottom was taken. A mechanical bucket was then used to remove the cut material.

different between the two studies, in general, the results of the Kill Van Kull investigation were similar to those observed in Calumet Harbor.

Peak estimates of TSS concentrations directly attributable to the cutterhead dredging operation in the Kill Van Kull did not exceed 200 mg/L and quickly dissipated to concentrations of less than 120 mg/L within approximately 374 meters of the source and to essentially background conditions by 500 meters down current. Of note, the plume was strictly confined to the lower quarter of the water column, and because the prevailing currents within the Kill Van Kull are strongly oriented along the channel, the plume did not extend beyond the channel bottom or into adjacent shallow water areas. This is expected given that the rocky material being excavated was not removed from the channel bottom by the cutterhead (i.e. this was accomplished using the excavator dredge) and that the overlying sediments were predominantly fine and medium grain-sized sand (Table 3) which would be expected to quickly fall out of suspension. As noted above, direct comparisons between suspended sediment studies can be inexact and difficult to interpret, particularly when comparing different dredge types. However, similar to previous studies of environmental or "closed" clamshell buckets within the Arthur Kill (USACE 2007a), Newark Bay (USACE 2008 and USACE 2009) and Port Elizabeth Channel (USACE 2010), the cutterhead plume remained within the channel boundaries, but was observed to be restricted to the lower portion of the water column than in these previous studies of closed buckets.

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Table 1. Laboratory Results of Water Samples

Sample	Sample Date	Sample Time	Location	Total Suspended Solids (mg/L)	Turbidity (NTU)
1	03/23/2011	10:26:11	Plume	168	48
2	03/23/2011	10:26:12	Plume	131	60
3	03/23/2011	10:26:14	Plume	169	58
4	03/23/2011	10:26:15	Plume	125	62
5	03/23/2011	10:26:17	Plume	158	57
6	03/23/2011	10:26:19	Plume	168	60
7	03/23/2011	10:37:41	Plume	120	37
8	03/23/2011	10:37:42	Plume	149	43
9	03/23/2011	10:37:44	Plume	128	45
10	03/23/2011	10:38:04	Plume	66	10
11	03/23/2011	10:38:06	Plume	77.5	13
12	03/23/2011	10:38:07	Plume	85.5	19
13	03/23/2011	10:47:32	Plume	84.5	9
14	03/23/2011	10:47:35	Plume	102	8
15	03/23/2011	10:47:51	Plume	65.5	11
16	03/23/2011	10:47:54	Plume	73	10
17	03/23/2011	10:48:14	Plume	42	19
18	03/23/2011	10:48:16	Plume	56.5	20
19	03/23/2011	11:02:23	Plume	77.5	13
20	03/23/2011	11:02:26	Plume	77	10
21	03/23/2011	11:02:29	Plume	41	12
22	03/23/2011	11:02:43	Plume	55.5	11
23	03/23/2011	11:02:44	Plume	68.5	11
24	03/23/2011	11:02:46	Plume	76.5	12
25	03/23/2011	12:18:20	Plume	51	11
26	03/23/2011	12:18:22	Plume	40	9
27	03/23/2011	12:18:40	Plume	49.5	6
28	03/23/2011	12:18:42	Plume	61	6
29	03/23/2011	12:19:03	Plume	73.5	6
30	03/23/2011	12:19:05	Plume	59	6
31	03/23/2011	12:26:35	Plume	41	19
32	03/23/2011	12:26:37	Plume	47	19
33	03/23/2011	12:27:07	Plume	68	6
34	03/23/2011	12:27:08	Plume	61	5
35	03/23/2011	12:27:35	Plume	68.5	6
36	03/23/2011	12:27:37	Plume	34	7
37	03/23/2011	13:24:28	Plume	28	5

Table 1. Laboratory Results of Water Samples

Sample	Sample Date	Sample Time	Location	Total Suspended Solids (mg/L)	Turbidity (NTU)
38	03/23/2011	13:24:29	Plume	30	4
39	03/23/2011	13:24:52	Plume	40.5	6
40	03/23/2011	13:24:53	Plume	41.5	5
41	03/23/2011	13:25:10	Plume	44.5	6
42	03/23/2011	13:25:12	Plume	20.5	6
43	03/23/2011	13:32:34	Plume	19.5	6
44	03/23/2011	13:32:36	Plume	26	6
45	03/23/2011	13:32:52	Plume	43	10
46	03/23/2011	13:32:54	Plume	34	9
47	03/23/2011	13:33:10	Plume	21.5	8
48	03/23/2011	13:33:13	Plume	24	8
49	03/23/2011	14:07:54	Plume	48.5	29
50	03/23/2011	14:07:56	Plume	70.5	30
51	03/23/2011	14:07:58	Plume	65.5	30
52	03/23/2011	14:07:59	Plume	71.5	31
53	03/23/2011	14:08:01	Plume	62	32
54	03/23/2011	14:08:03	Plume	65.5	31
55	03/23/2011	14:18:43	Plume	48.5	29
56	03/23/2011	14:18:45	Plume	66.5	27
57	03/23/2011	14:18:46	Plume	54.5	27
58	03/23/2011	14:18:52	Plume	61	30
59	03/23/2011	14:18:53	Plume	43.5	26
60	03/23/2011	14:18:54	Plume	56	26
61	03/23/2011	14:32:20	Plume	79.5	38
62	03/23/2011	14:32:21	Plume	82	41
63	03/23/2011	14:32:24	Plume	87.5	37
64	03/23/2011	14:32:39	Plume	36	21
65	03/23/2011	14:32:40	Plume	44.5	25
66	03/23/2011	14:32:42	Plume	42	25
67	03/23/2011	14:49:47	Plume	21.5	11
68	03/23/2011	14:49:48	Plume	34.5	14
69	03/23/2011	14:49:50	Plume	34	13
70	03/23/2011	14:50:02	Plume	42	24
71	03/23/2011	14:50:03	Plume	42.5	19
72	03/23/2011	14:50:04	Plume	40.5	18
73	03/24/2011	12:07:44	Ambient	39.5	7
74	03/24/2011	12:07:45	Ambient	70.5	7

Table 1. Laboratory Results of Water Samples

Sample	Sample Date	Sample Time	Location	Total Suspended Solids (mg/L)	Turbidity (NTU)
75	03/24/2011	12:08:05	Ambient	41.5	8
76	03/24/2011	12:08:07	Ambient	49.5	7
77	03/24/2011	12:08:28	Ambient	43	20
78	03/24/2011	12:08:30	Ambient	44.5	20
79	03/24/2011	12:16:38	Ambient	34	7
80	03/24/2011	12:16:40	Ambient	18.5	7
81	03/24/2011	12:17:04	Ambient	47	9
82	03/24/2011	12:17:06	Ambient	48	9
83	03/24/2011	12:17:24	Ambient	48.5	18
84	03/24/2011	12:17:26	Ambient	49.5	19
85	03/24/2011	12:25:11	Ambient	65	6
86	03/24/2011	12:25:12	Ambient	47	5
87	03/24/2011	12:25:37	Ambient	55	5
88	03/24/2011	12:25:40	Ambient	34	7
89	03/24/2011	12:25:57	Ambient	39.5	13
90	03/24/2011	12:25:59	Ambient	43	15
91	03/25/2011	12:02:55	Ambient	67	8
92	03/25/2011	12:02:57	Ambient	59	8
93	03/25/2011	12:03:16	Ambient	50	10
94	03/25/2011	12:03:17	Ambient	63	11
95	03/25/2011	12:03:39	Ambient	31	17
96	03/25/2011	12:03:41	Ambient	39	16
97	03/25/2011	12:09:25	Ambient	53	6
98	03/25/2011	12:09:27	Ambient	58.5	5
99	03/25/2011	12:09:43	Ambient	66.5	6
100	03/25/2011	12:09:44	Ambient	66.5	5
101	03/25/2011	12:10:03	Ambient	40.5	14
102	03/25/2011	12:10:05	Ambient	50	12
103	03/25/2011	12:15:25	Ambient	58	7
104	03/25/2011	12:15:26	Ambient	67.5	7
105	03/25/2011	12:15:43	Ambient	39	13
106	03/25/2011	12:15:45	Ambient	43.5	13
107	03/25/2011	12:15:56	Ambient	45	16
108	03/25/2011	12:15:59	Ambient	38	18

Table 2. 23 March 2011 Far Field Flood Tide Survey - Transect Summary

Transect Number	Figure Number	Time	Transect Length (m)	Distance From Dredge (m)	Plume Description	Additional Field Remarks
A01	3a	12:05:05	429	281	Ambient Transects	Distance to stern of Florida, 2nd dredge in-between
A02	3b	12:08:51	394	339		
A03	3c	12:12:38	449	501		
C01	3d	09:30:44	1,876	150	Circle transects, higher concentrations (100-140 mg/l) near bottom and closest to dredge	Circle around both dredges
C02	3e	09:44:23	1,548	150		
C03	3f	09:56:41	1,821	200		Ship wake
T01	3g	10:19:50	379	172	Plume in bottom of water column, up to 180 mg/l	Propwash
T02	3h	10:31:05	321	189	Plume continues on the bottom, concentrations up to 200 mg/l	
T03	3i	10:33:44	271	220		
T04	3j	10:40:22	293	248	Plume widens to more than 80m across	
T05	3k	10:42:57	245	293	Plume maintains shape and continues to dissipate	
T06	3l	10:51:38	353	248		Ship wake at end
T07	3m	10:54:58	249	374		Ship wake at beginning
T08	3n	10:57:21	290	416		
T09	3o	11:05:59	311	435		
T10	3p	11:08:25	445	440		
T11	3q	11:14:53	327	538		Waited for traffic, Possible ship wake on bottom
T12	3r	11:46:29	390	601	Appears to extend through most of the water column	Possible ship wake on bottom
T13	3s	11:50:39	318	646	Plume is wide and along the bottom	Possible ship wake on bottom, prop wash
T14	3t	11:53:30	258	720		Possible ship wake on bottom
T15	3u	11:56:16	204	811		

Table 3: Sediment Collection and Analysis Summary Table

Date Sampled	Sample ID	Time Sampled	Grain Size Distribution[1]						Density[2]	Atterberg Limits[3]		
			Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt	Clay	In Place Density	Liquid Limit	Plastic Limit	Plasticity Index
			(%)	(%)	(%)	(%)	(%)	(%)	(g/cc)	--	--	--
03/23/2011	41128	15:30	0	0	4.7	70.4	17.5	7.4	1.26	0	0	NP
03/23/2011	41130	15:30	0	0	4.9	72.7	15.9	6.5	1.32	0	0	NP
03/23/2011	41131	15:30	0	0	4	69.8	19.5	6.7	1.31	0	0	NP
03/24/2011	41126	11:45	6.2	10.6	34.8	40.2	5.4	2.8	1.52	0	0	NP
03/24/2011	41129	11:45	7.6	7.4	30.4	45.6	5.4	3.7	1.47	0	0	NP
03/24/2011	42050	11:45	8.1	8.7	31.5	43.9	5.6	2.2	1.46	0	0	NP

[1] ASTM D-422 Method

[2] ASTM D-2937 Method

[3] ASTM D-4318 Method

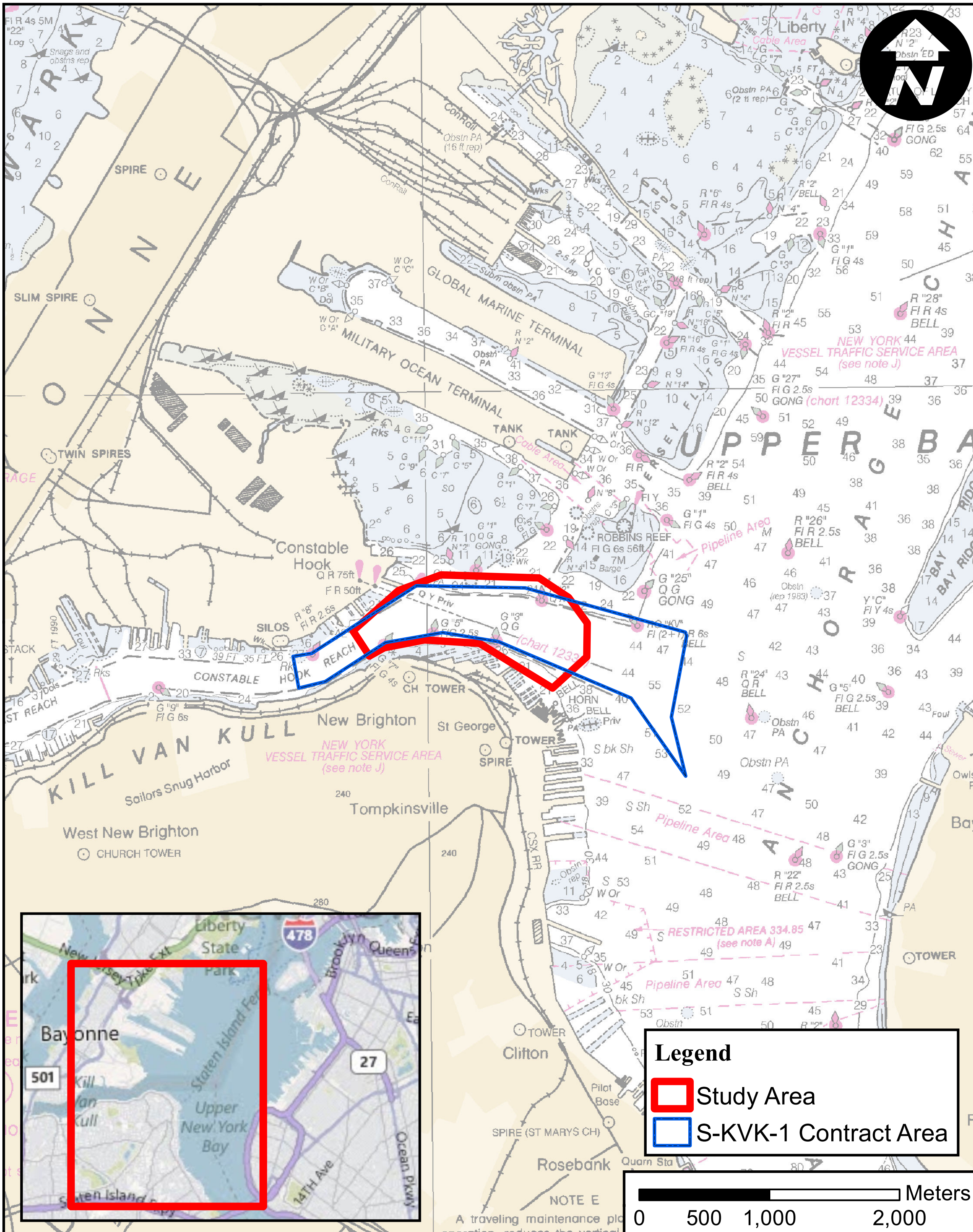


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Upper Bay - Kill Van Kull Channel S-KVK-1 Cutterhead Far Field Study Area	Tide
1			N/A

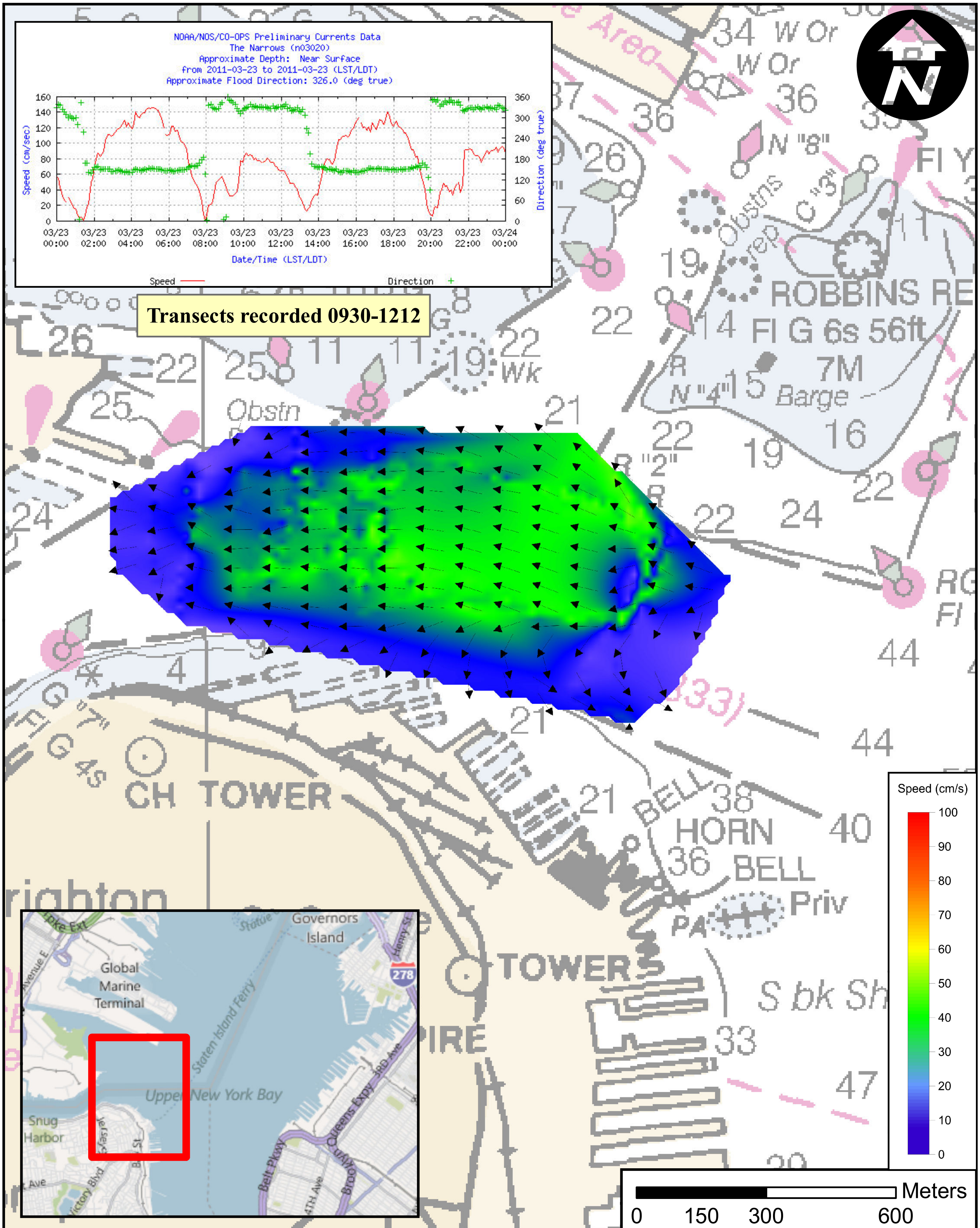


Figure	*USACE Harborwide TSS* *Far Field Survey* *KVK Cutterhead*	**Depth Averaged Velocities** **23 March 2011**	Tide
2a			Flood

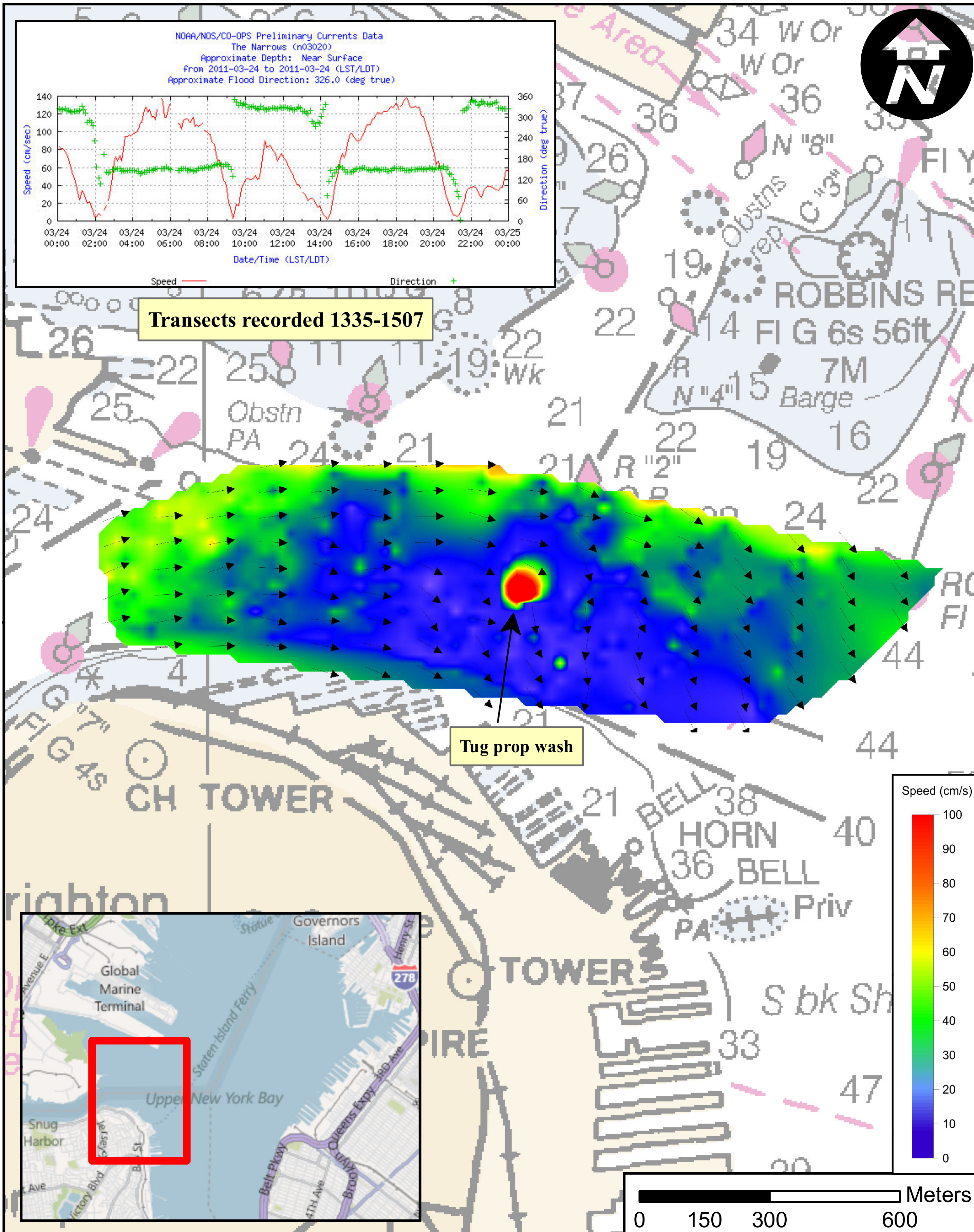


Figure	*USACE Harborwide TSS*	**Depth Averaged Velocities**	Tide
2b	*Far Field Survey* *KVK Cutterhead*	**24 March 2011**	**Ebb**

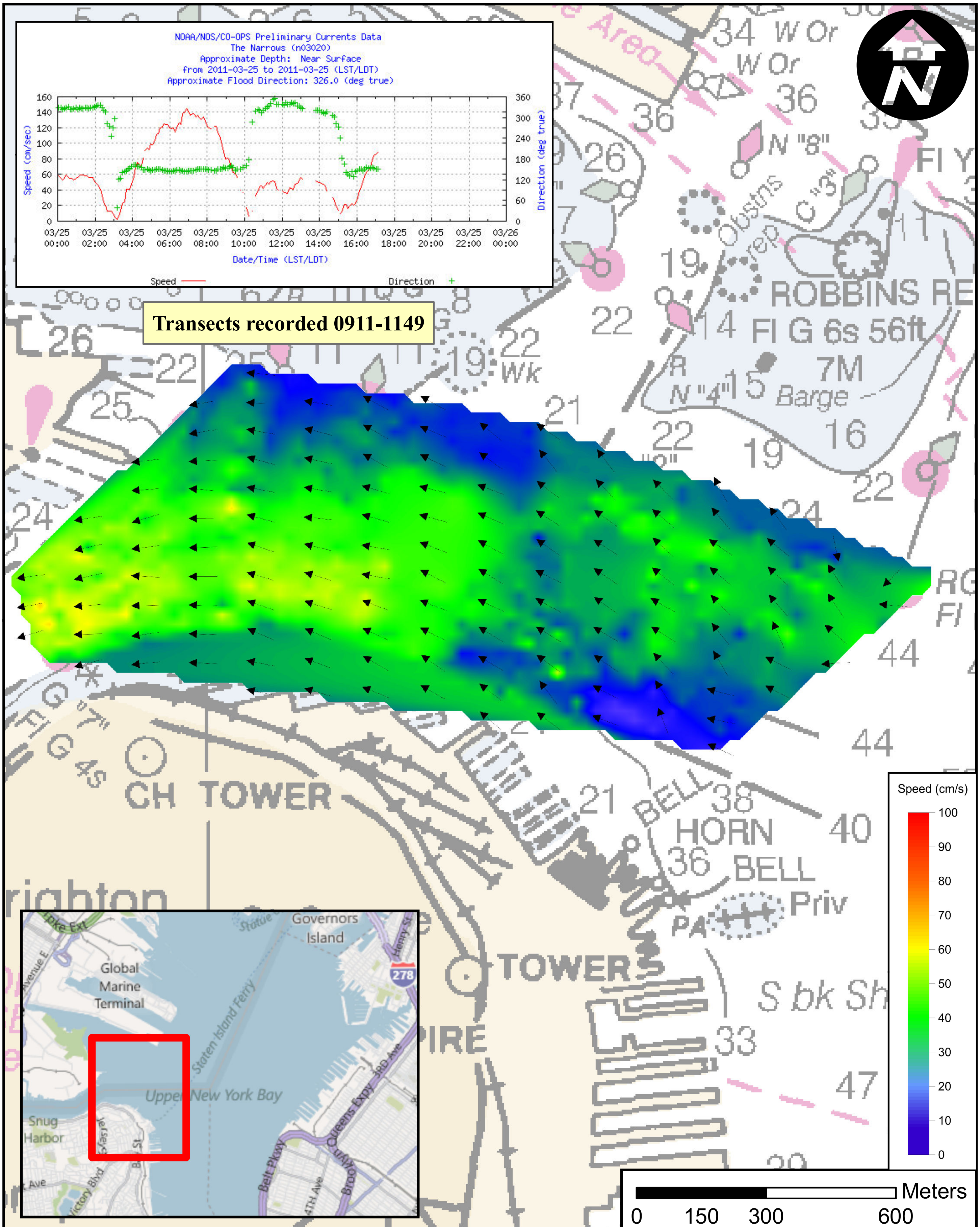


Figure	*USACE Harborwide TSS* *Far Field Survey* *KVK Cutterhead*	**Depth Averaged Velocities** **25 March 2011**	**Tide**
2c			**Flood**

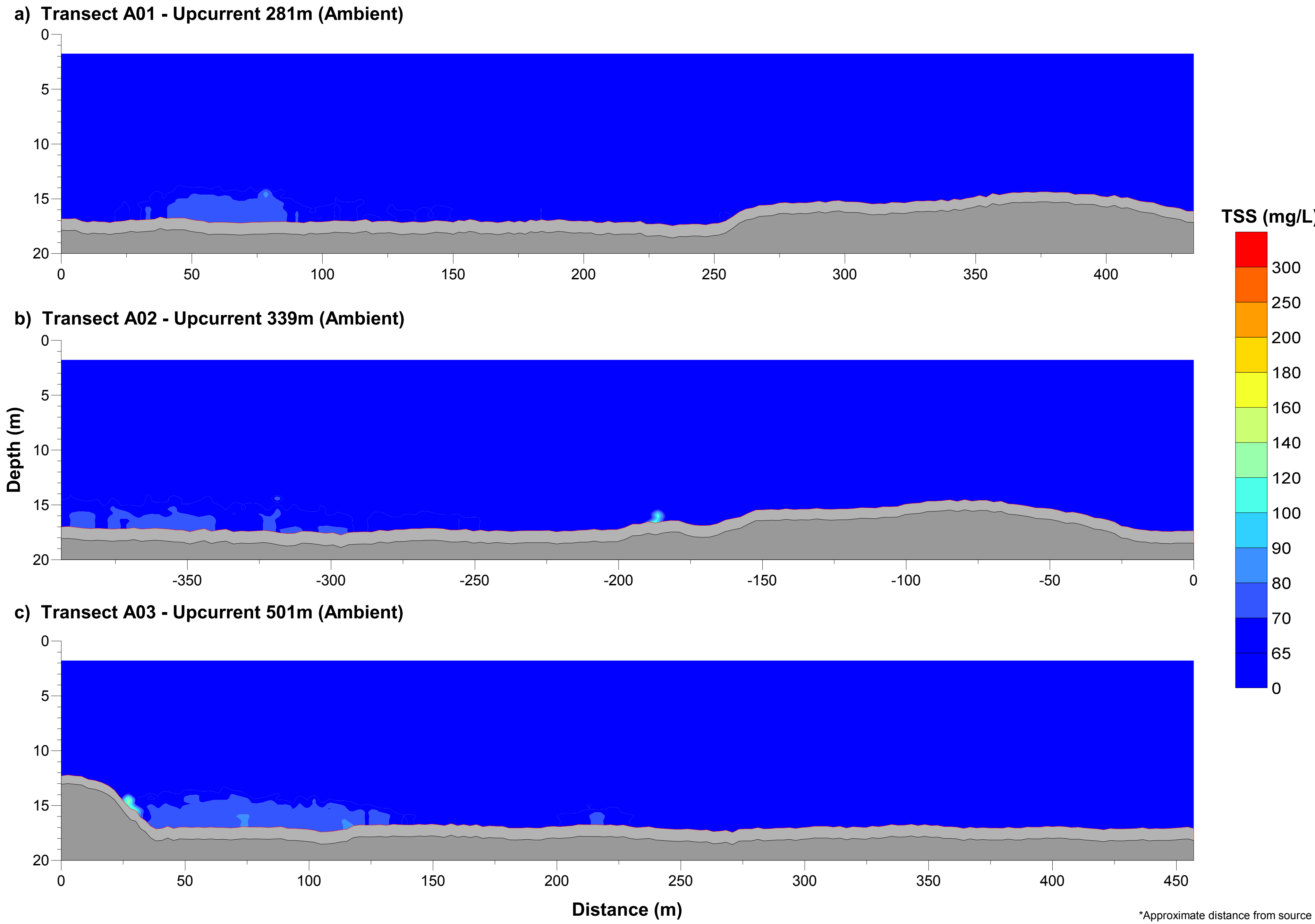


FIGURE	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Vertical Profiles of ADCP Average TSS 23 March 2011	TIDE
3a-c			Flood

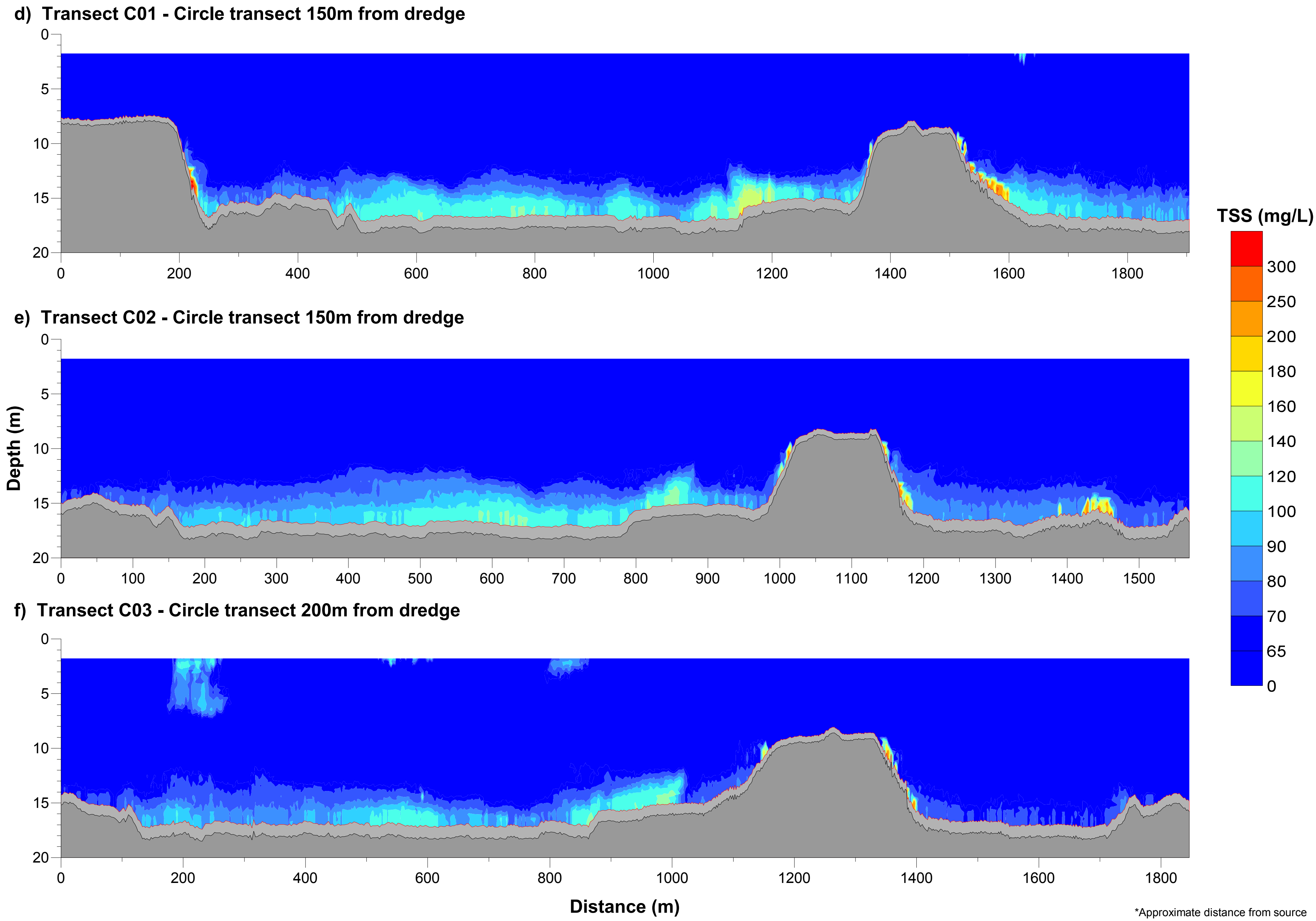


FIGURE	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Vertical Profiles of ADCP Average TSS 23 March 2011	TIDE
3d-f			Flood

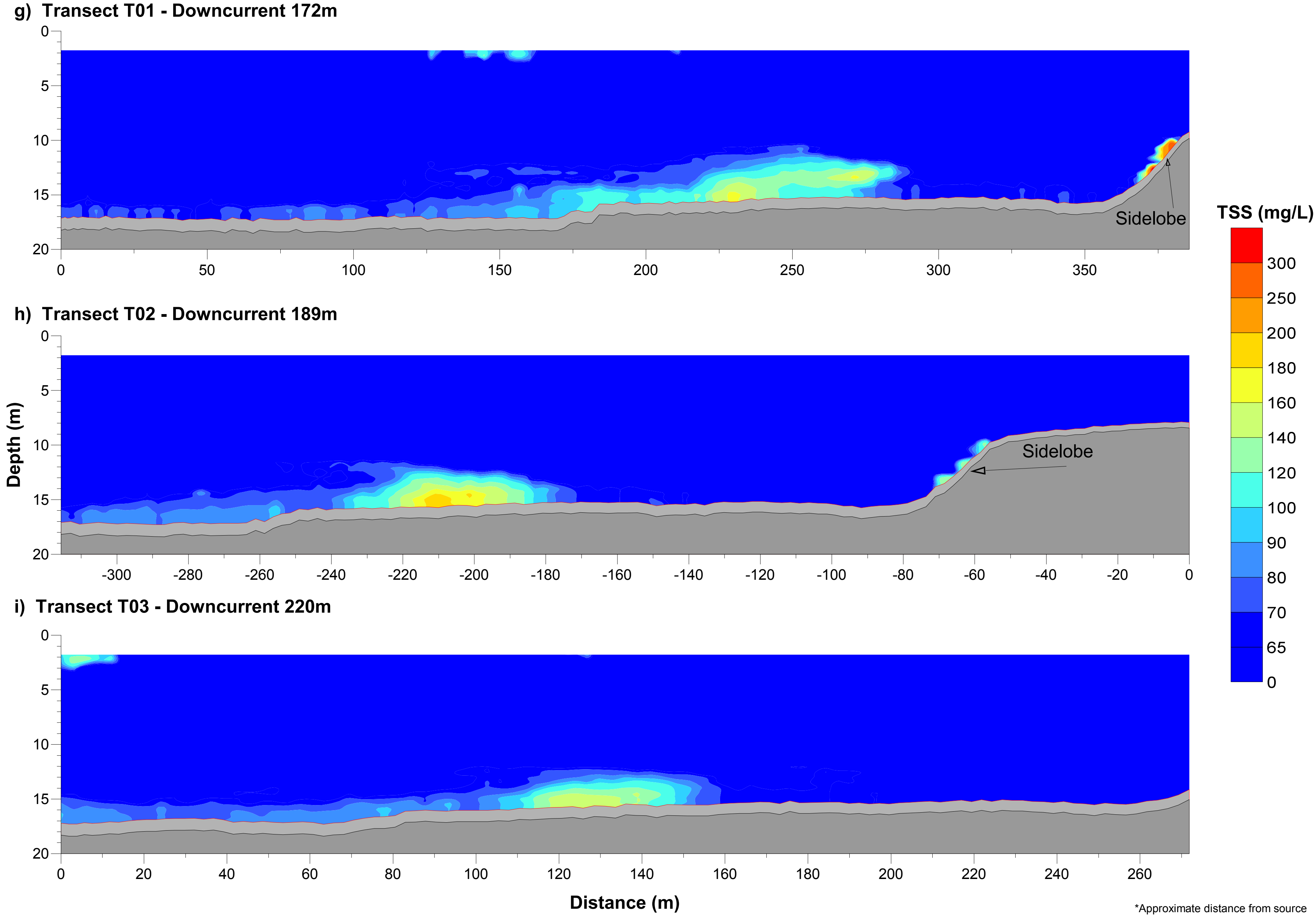


FIGURE	*USACE Harborwide TSS* *Far Field Survey* *KVK Cutterhead*	**Vertical Profiles of ADCP Average TSS** **23 March 2011**	TIDE
3g-i			**Flood**

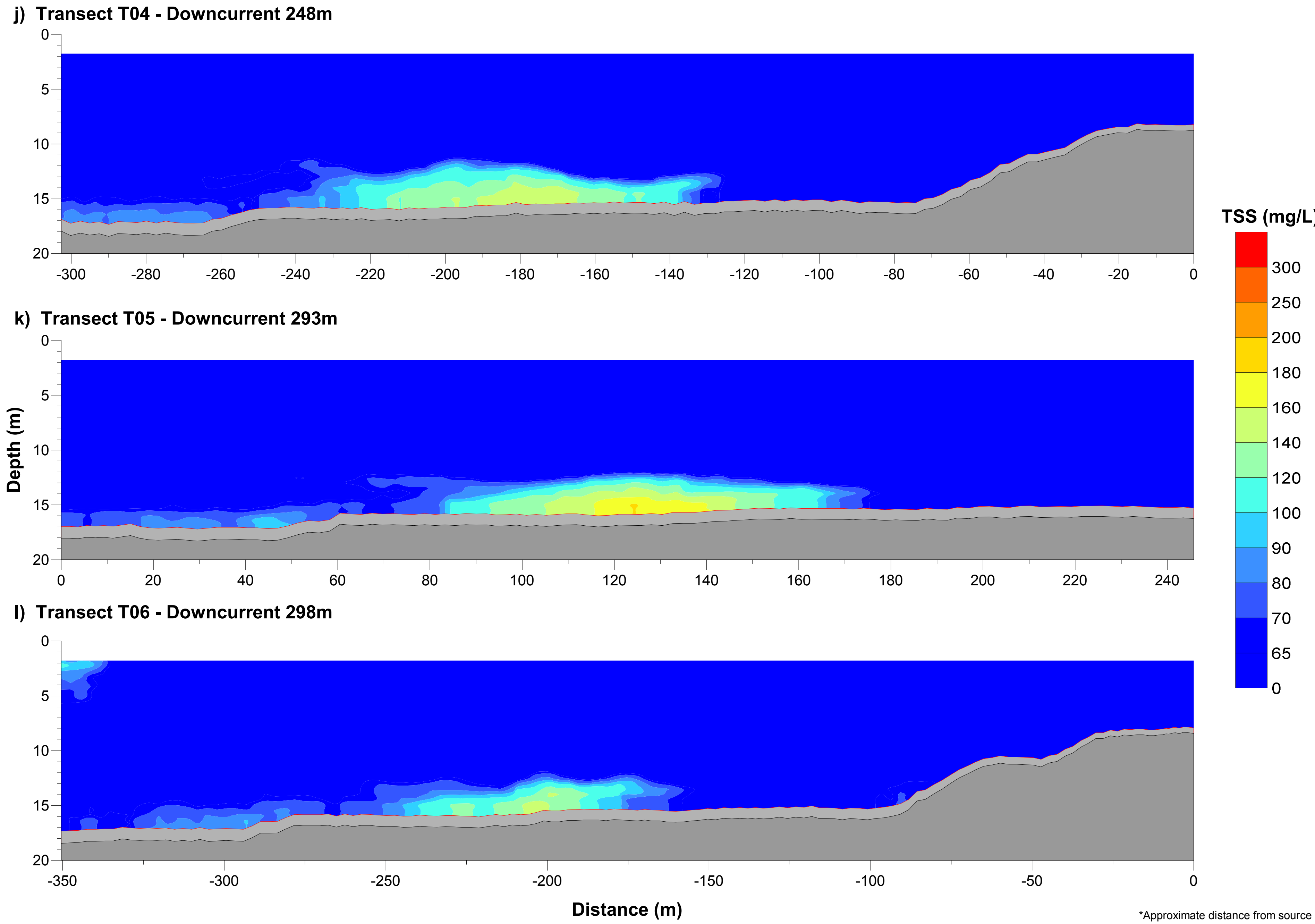


FIGURE	*USACE Harborwide TSS* *Far Field Survey* *KVK Cutterhead*	**Vertical Profiles of ADCP Average TSS** **23 March 2011**	TIDE
3j-l			Flood

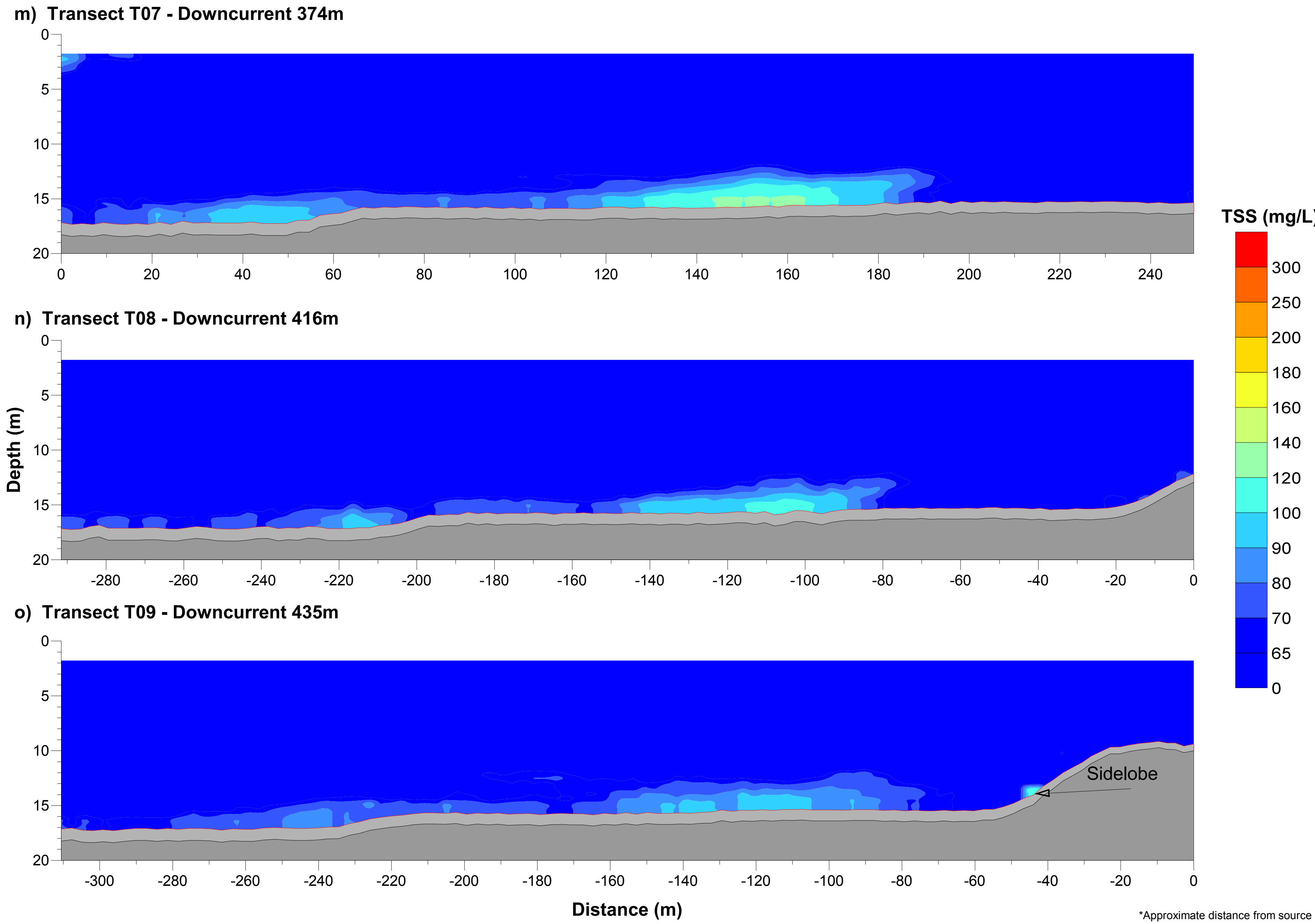
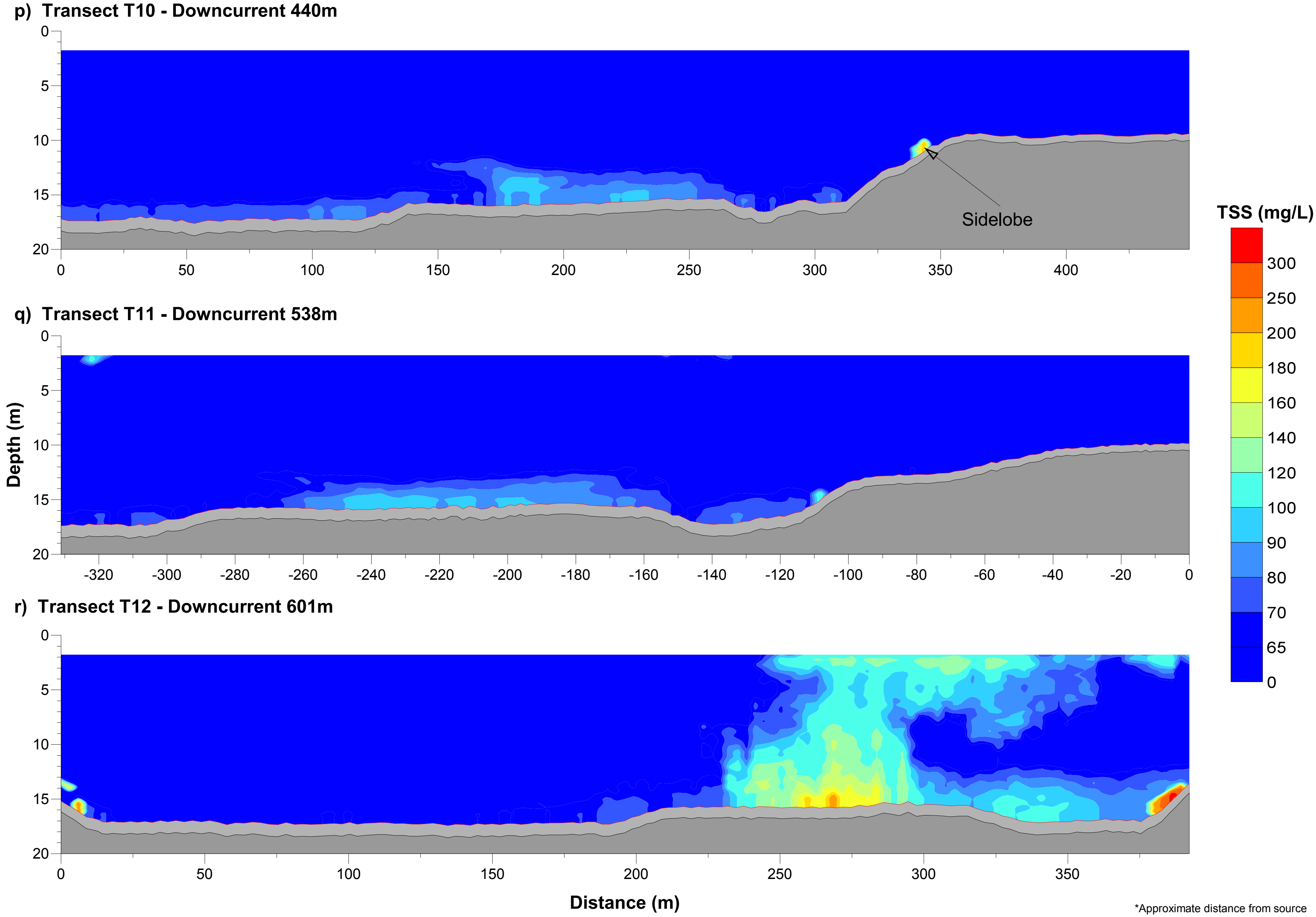


FIGURE	*USACE Harborwide TSS*	**Vertical Profiles of ADCP Average TSS**	TIDE
3m-o	*Far Field Survey* *KVK Cutterhead*	**23 March 2011**	**Flood**



*Approximate distance from source

FIGURE	*USACE Harborwide TSS Far Field Survey KVK Cutterhead*	**Vertical Profiles of ADCP Average TSS 23 March 2011**	TIDE
3p-r			**Flood**

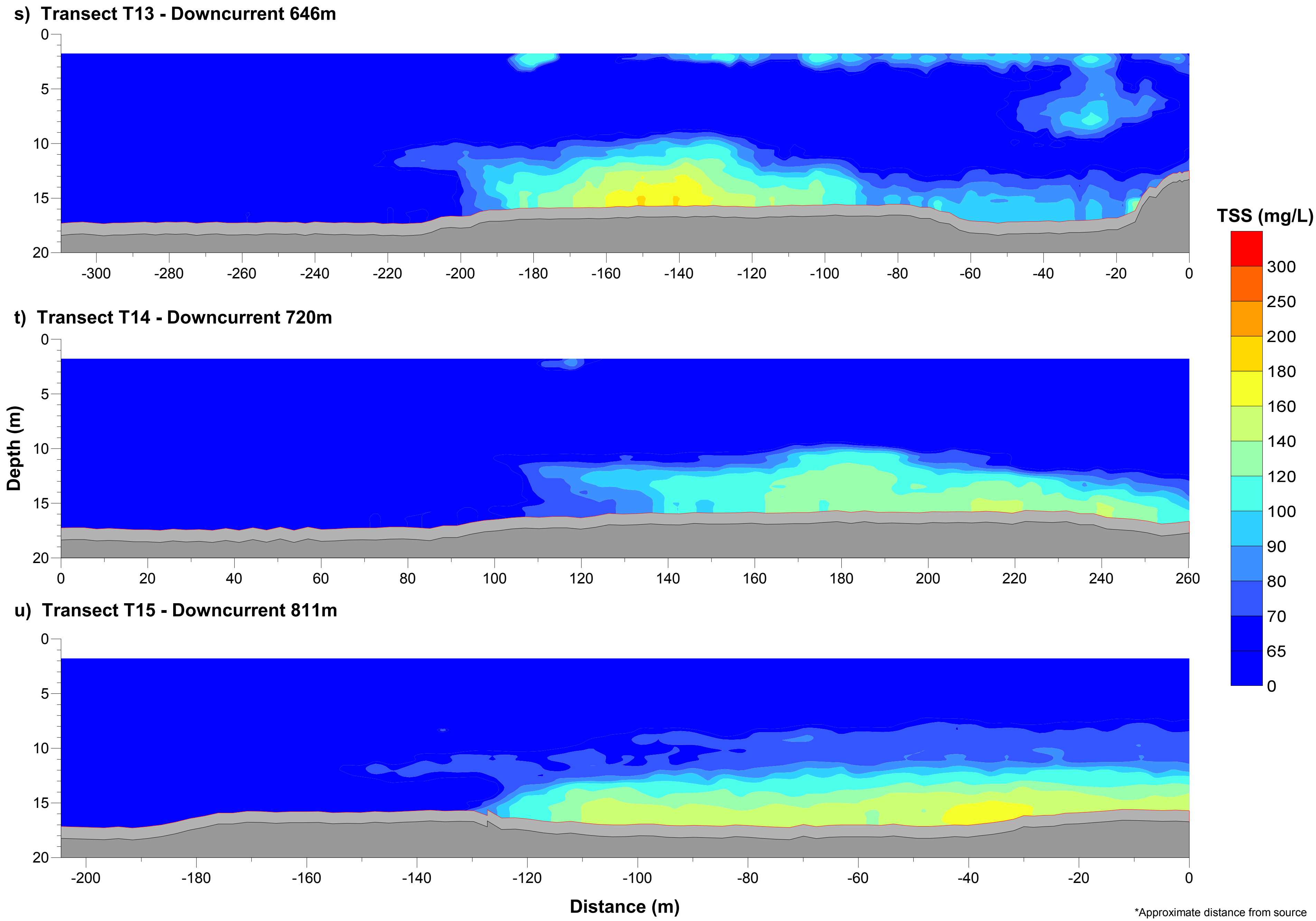


FIGURE	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Vertical Profiles of ADCP Average TSS 23 March 2011	TIDE
3s-u			Flood

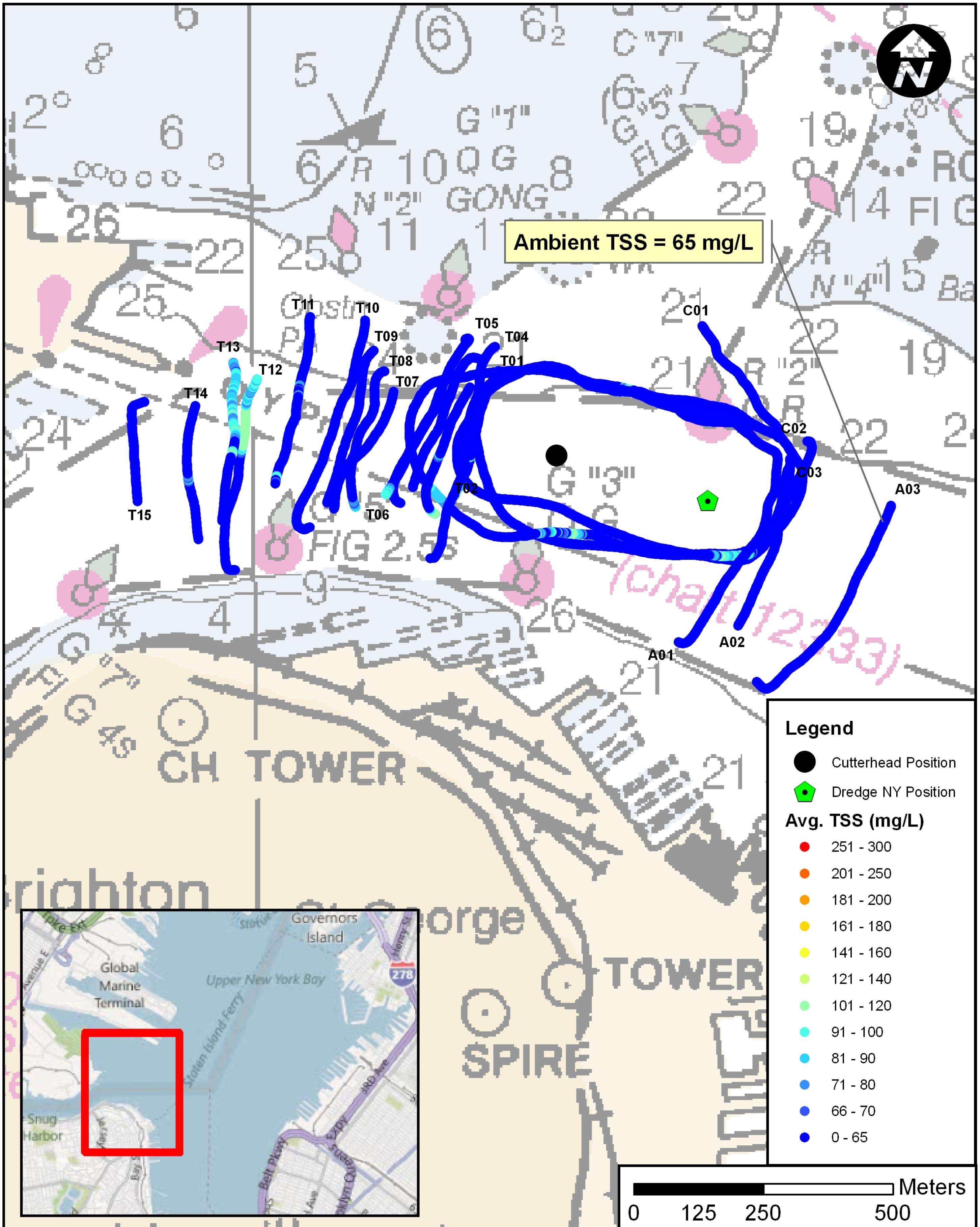


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	ADCP Average TSS - 23 March 2011 0-2 Meter Depth Interval	Tide
4a			Flood

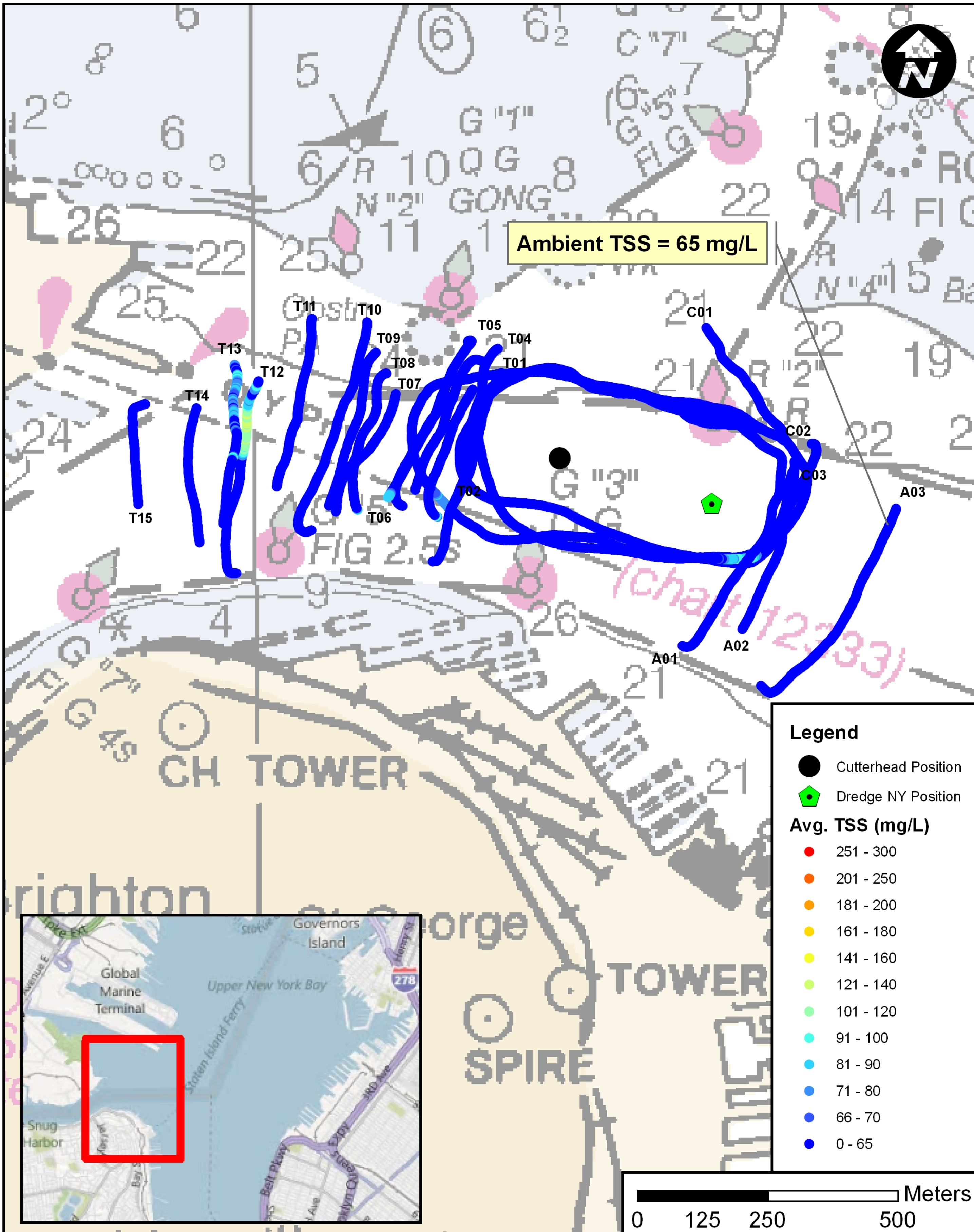


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	ADCP Average TSS - 23 March 2011 2-4 Meter Depth Interval	Tide
4b			Flood

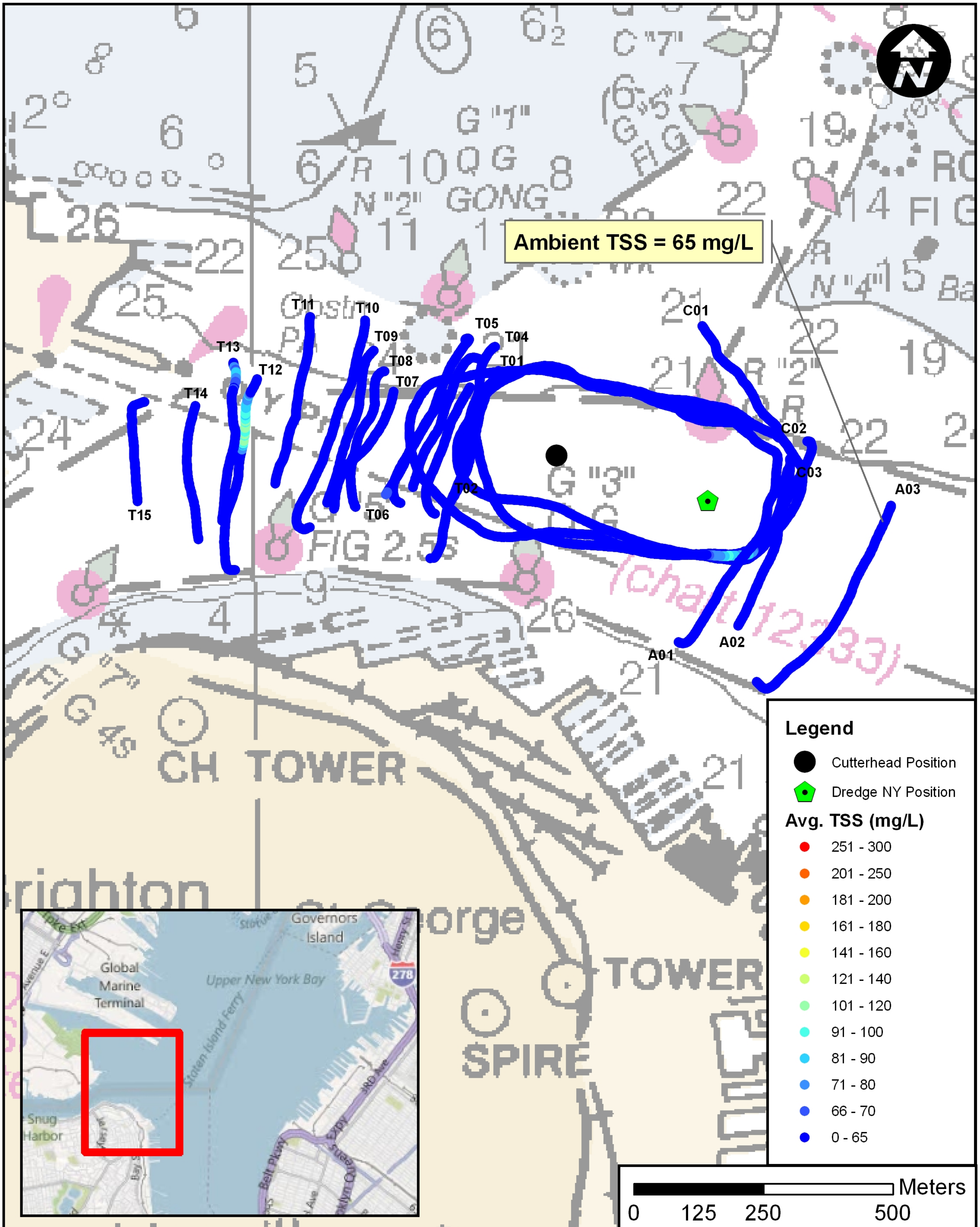


Figure	*USACE Harborwide TSS* *Far Field Survey* *KVK Cutterhead*	**ADCP Average TSS - 23 March 2011** **4-6 Meter Depth Interval**	**Tide**
4c			**Flood**

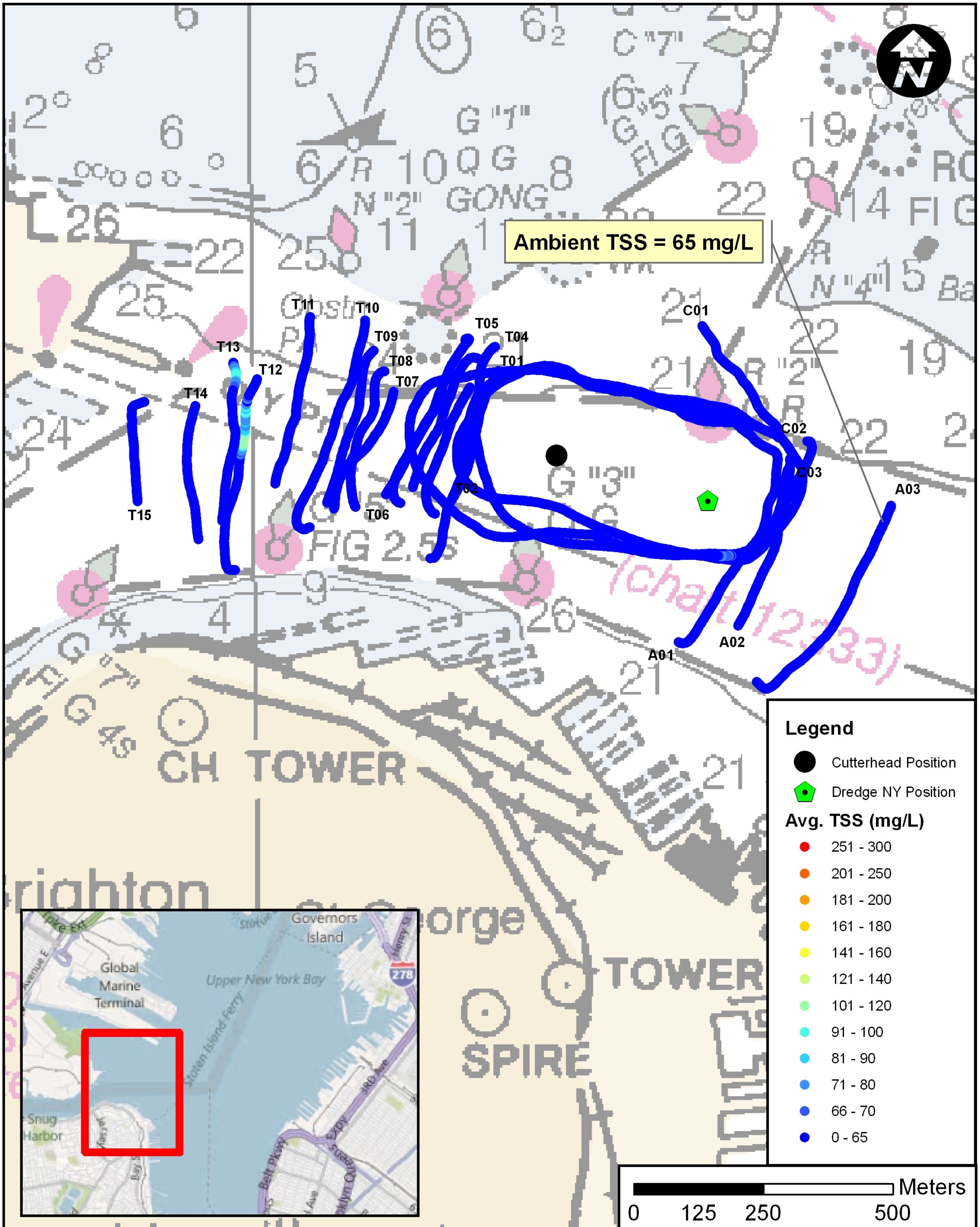


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	ADCP Average TSS - 23 March 2011 6-8 Meter Depth Interval	Tide
4d			Flood

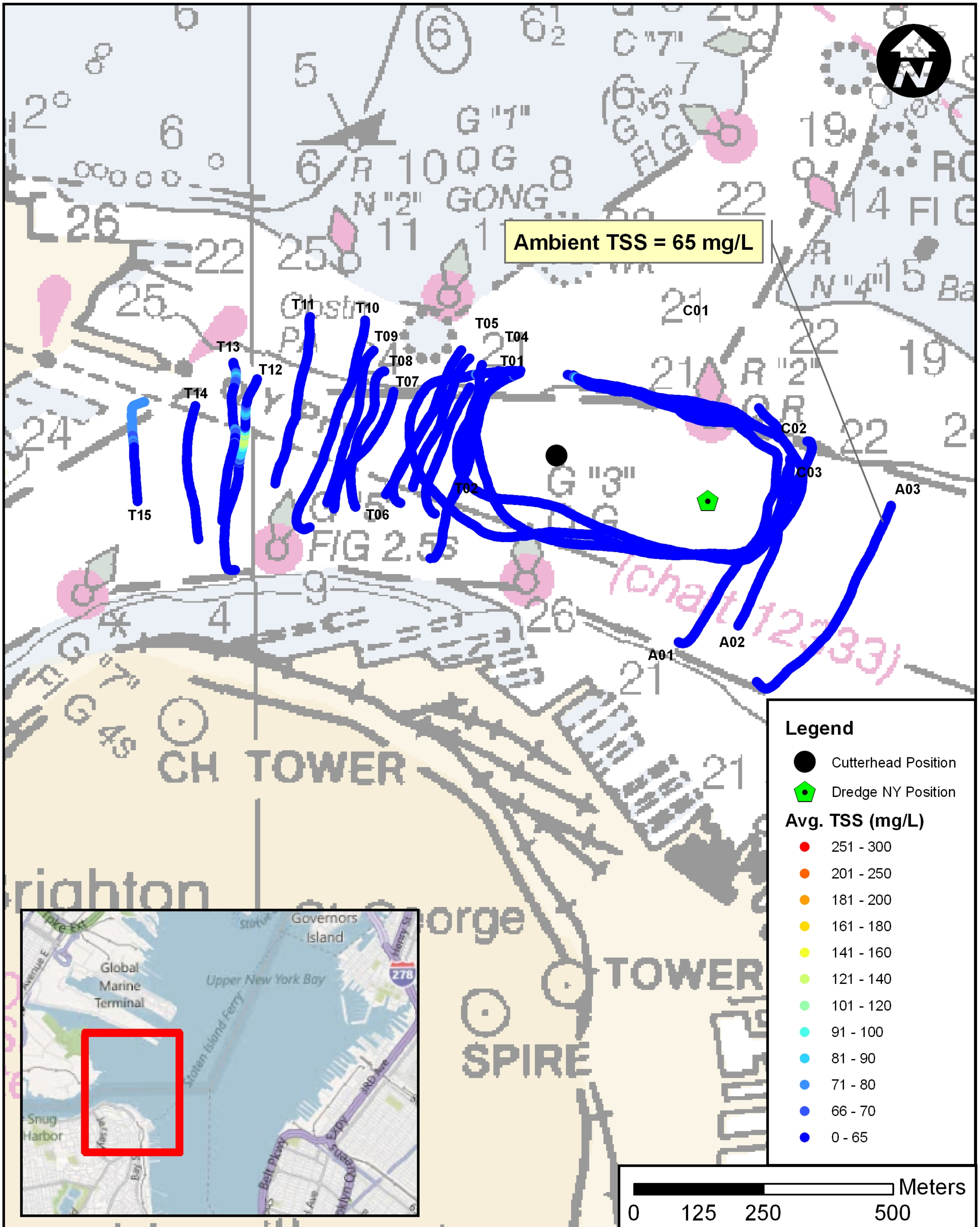


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	ADCP Average TSS - 23 March 2011 8-10 Meter Depth Interval	Tide
4e			Flood

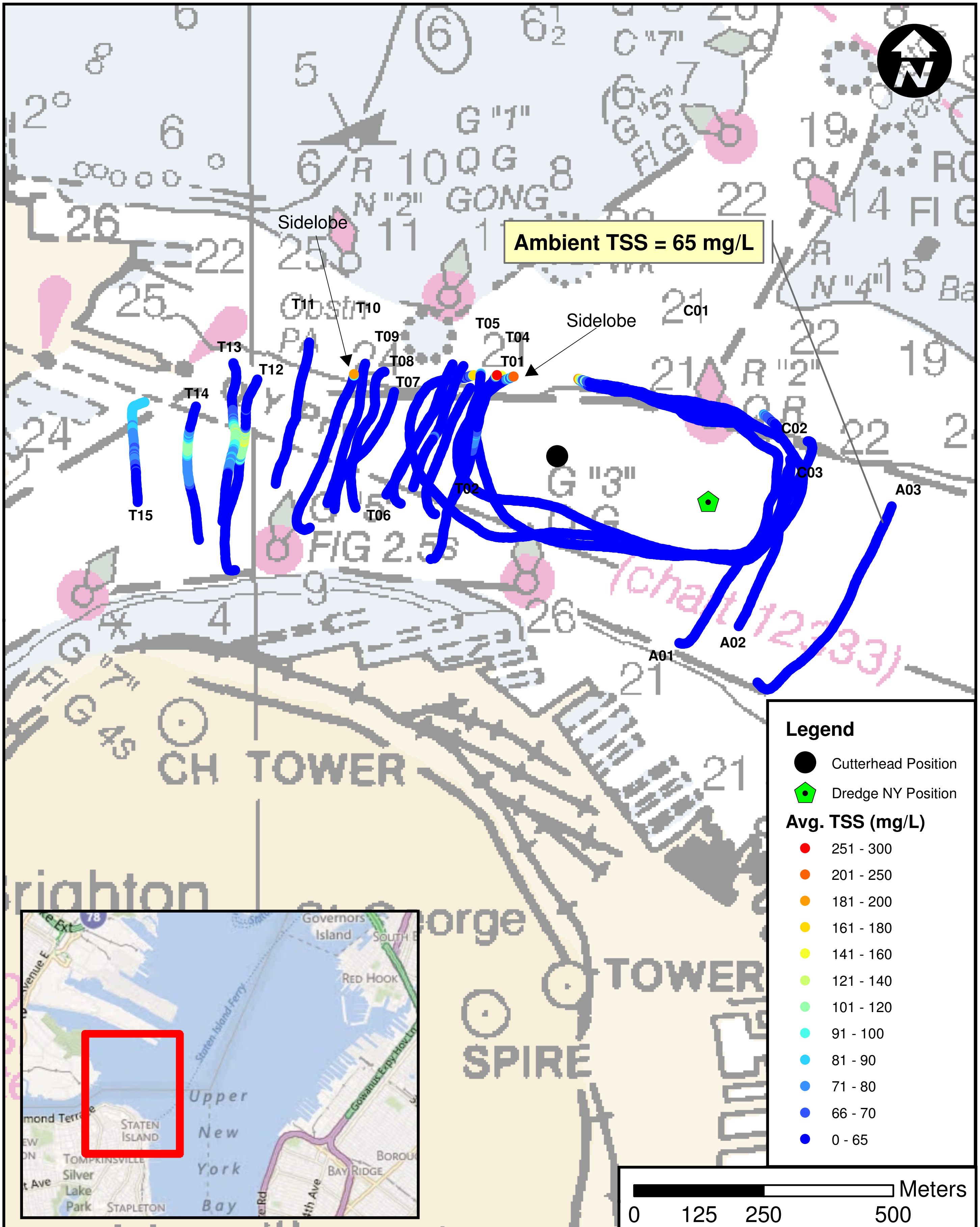


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	ADCP Average TSS - 23 March 2011 10-12 Meter Depth Interval	Tide
4f			Flood

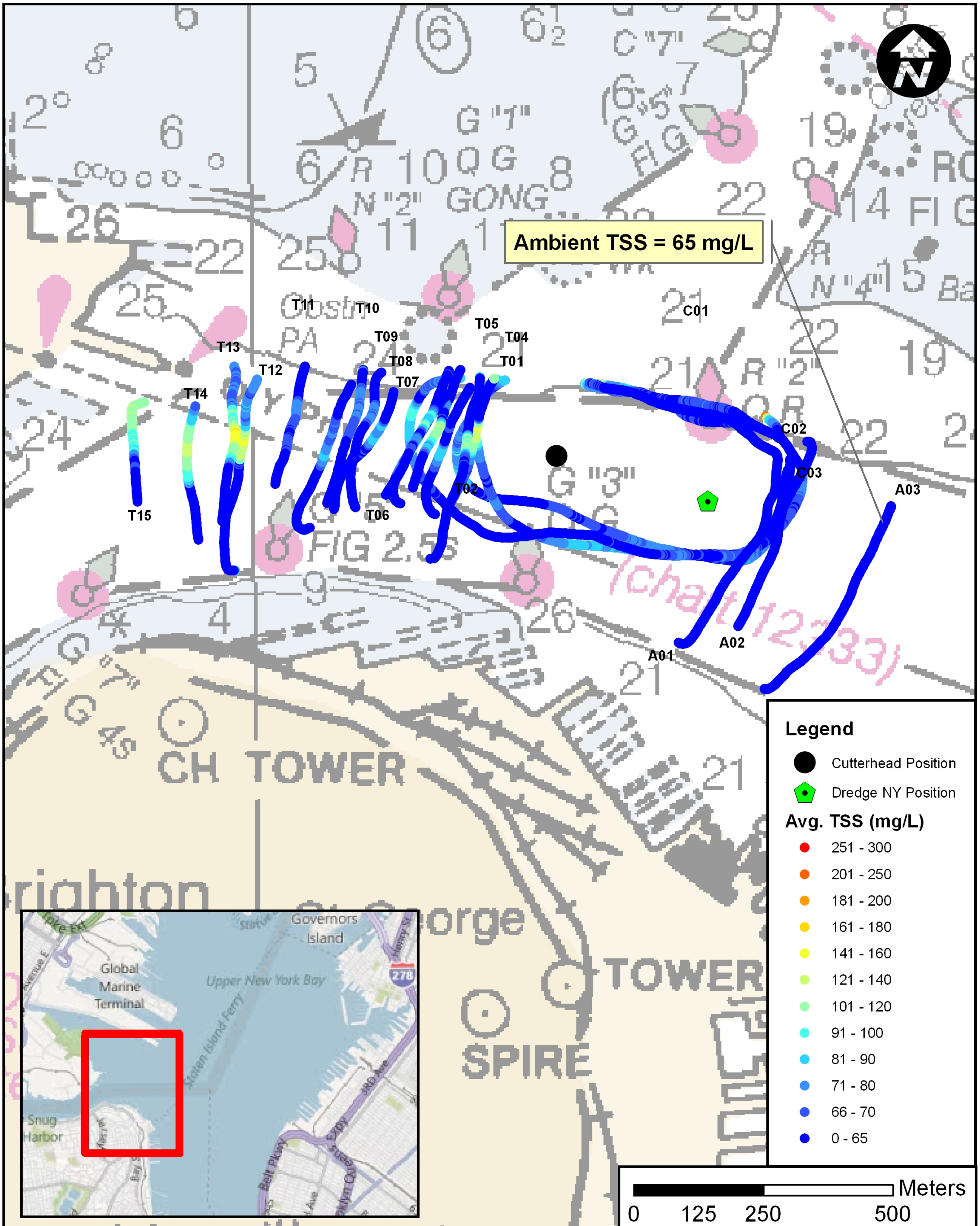


Figure	*USACE Harborwide TSS Far Field Survey KVK Cutterhead*	ADCP Average TSS - 23 March 2011 12-14 Meter Depth Interval	Tide
4g			Flood

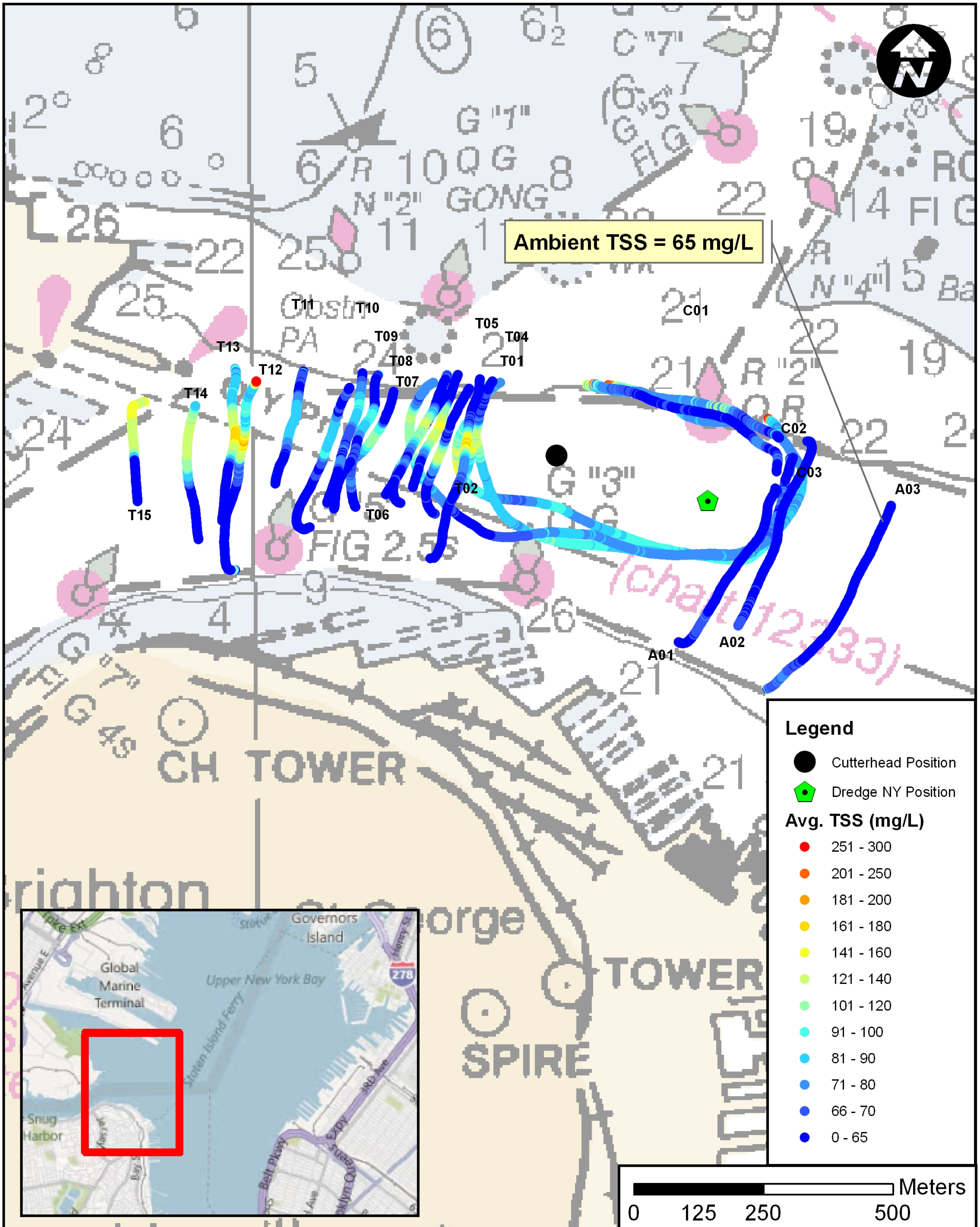
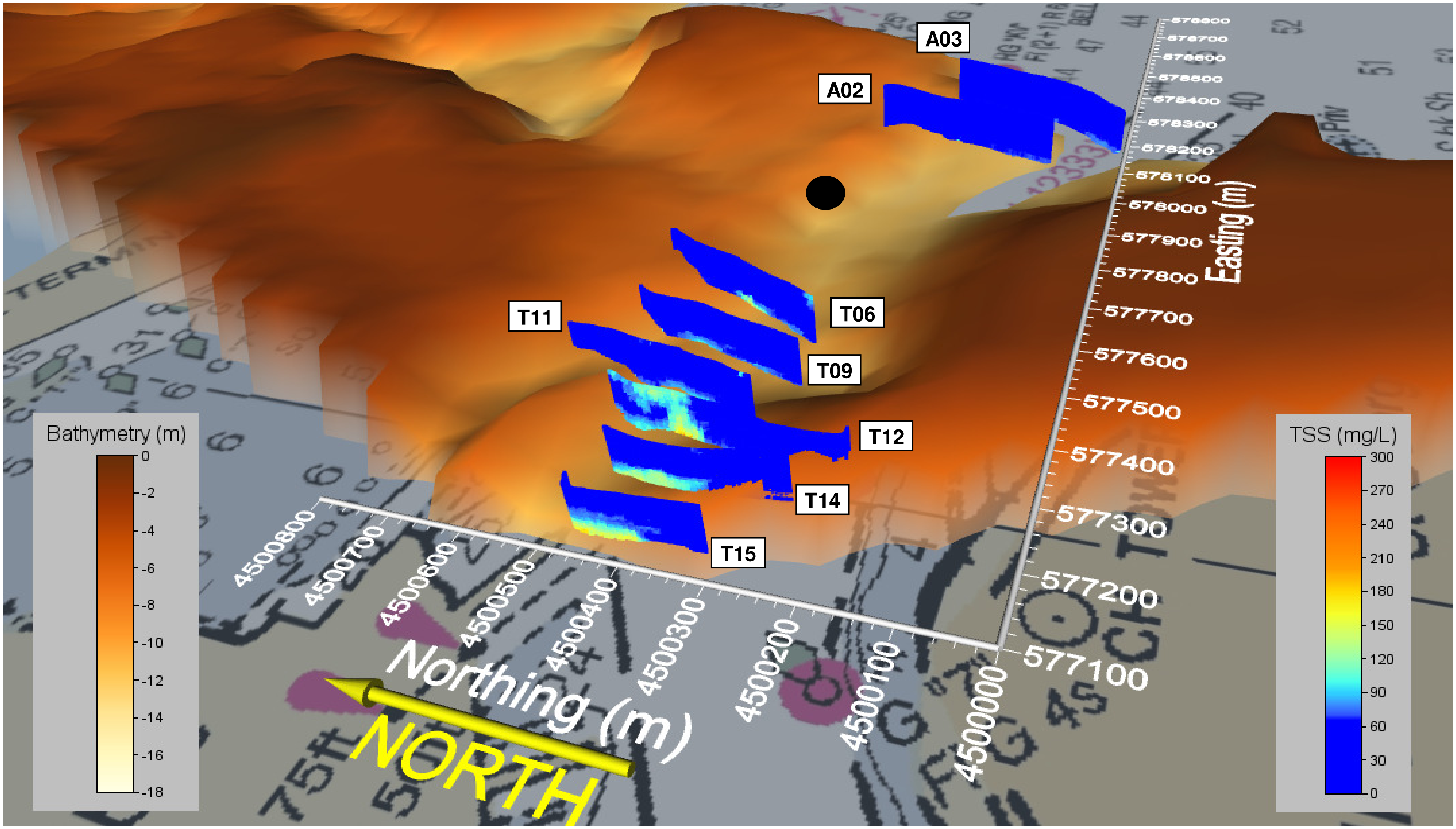


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	ADCP Average TSS - 23 March 2011 14-16 Meter Depth Interval	Tide
4h			Flood



Bathymetry produced from NOAA soundings

Z Scale Exaggerated 6x

● = Cutterhead Location

Figure	*USACE Harborwide TSS Far Field Survey KVK Cutterhead*	**ADCP Average TSS Values with Respect to their x, y, and z Coordinates Superimposed on Channel Bathymetry 23 March 2011**	Tide
5			Flood

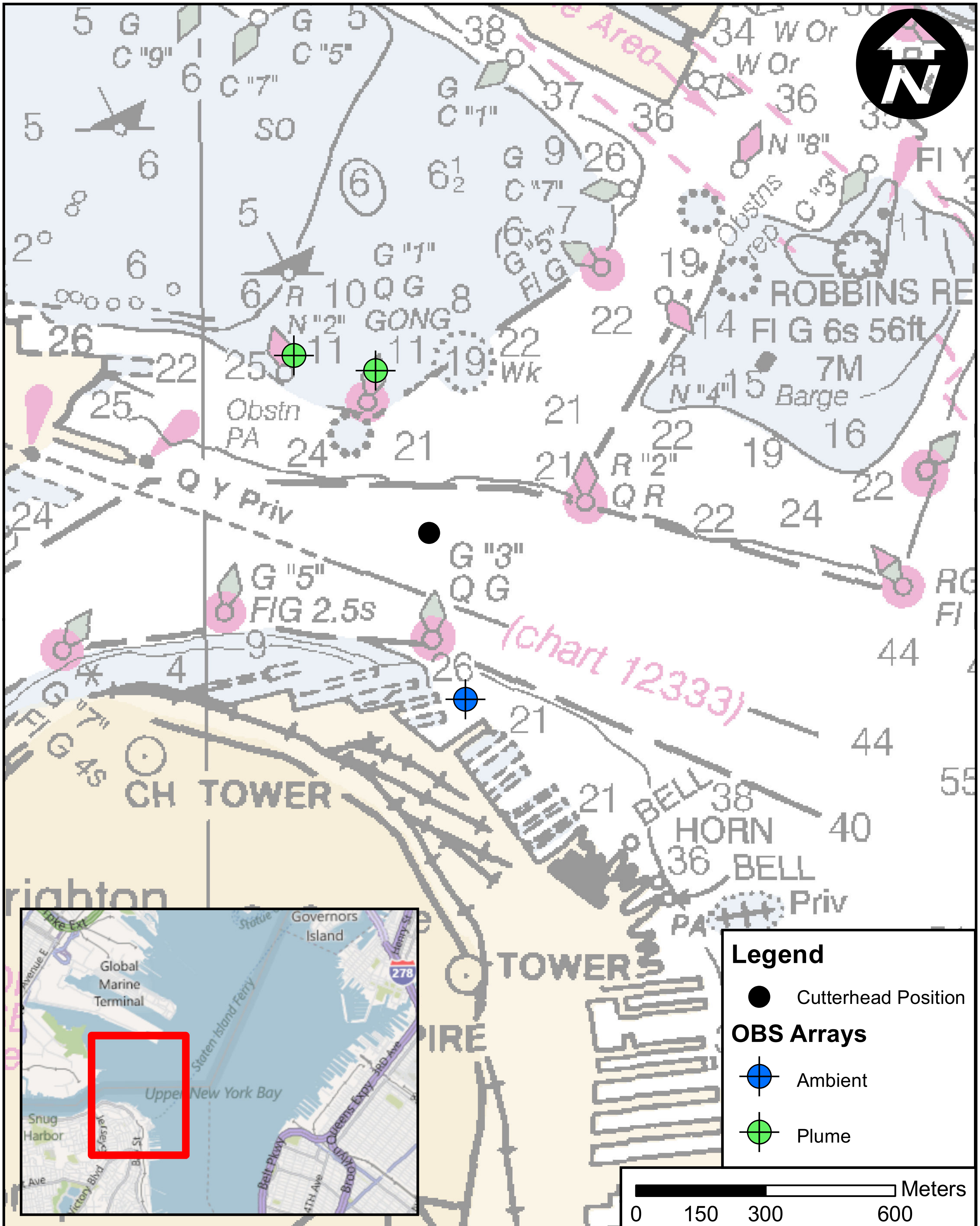
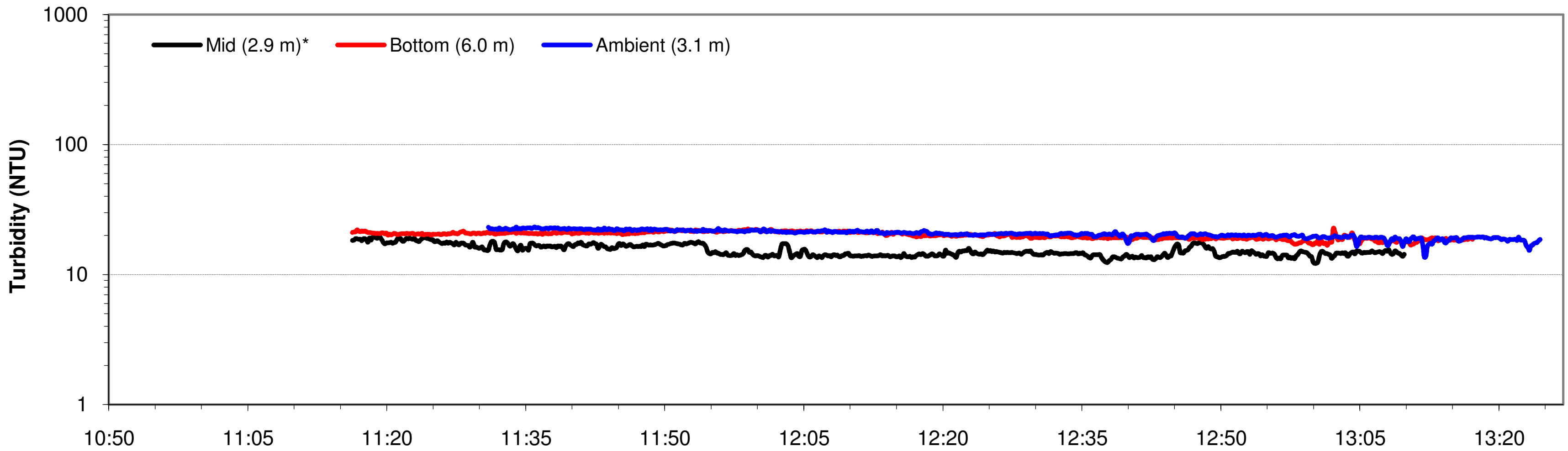
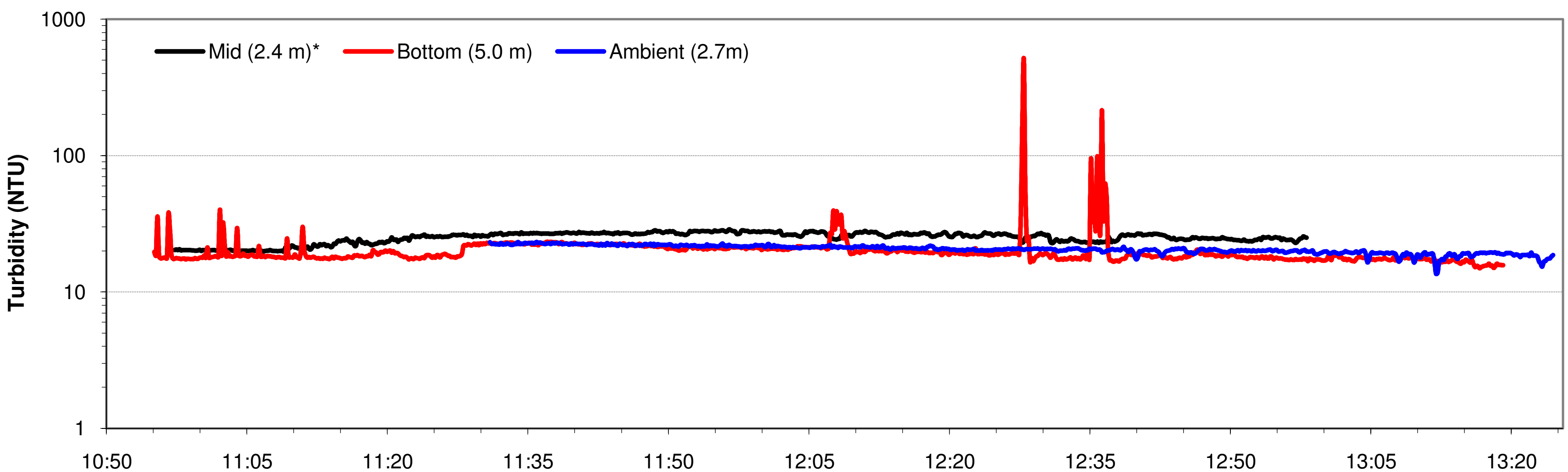


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Location of OBS Vertical Arrays with Respect to Dredge Position 24 March 2011	Tide
6			Flood

a) 405 meters Down Current from Dredge



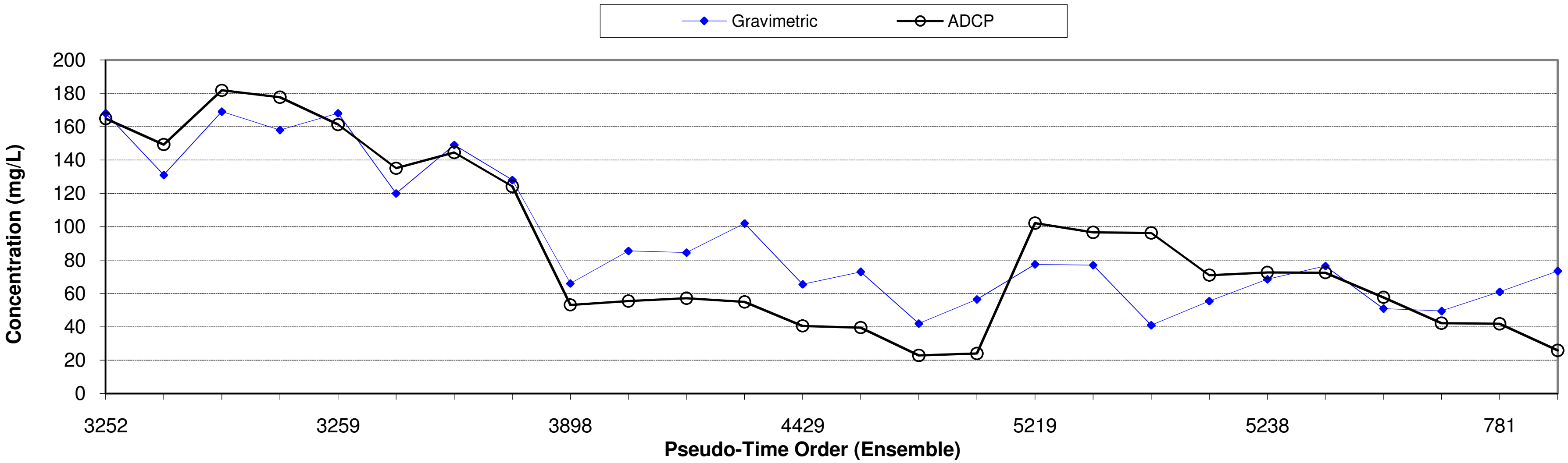
b) 530 meters Down Current from Dredge



*Number in parentheses is average depth of instrument over period recorded

Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Surface and Bottom OBS Turbidities at a) 405 m and b) 530 m Downcurrent of Dredge. Ambient Station Located 390m Upcurrent of Dredge 24 March 20011 TSS Survey	Tide
7			Flood

a)



b)

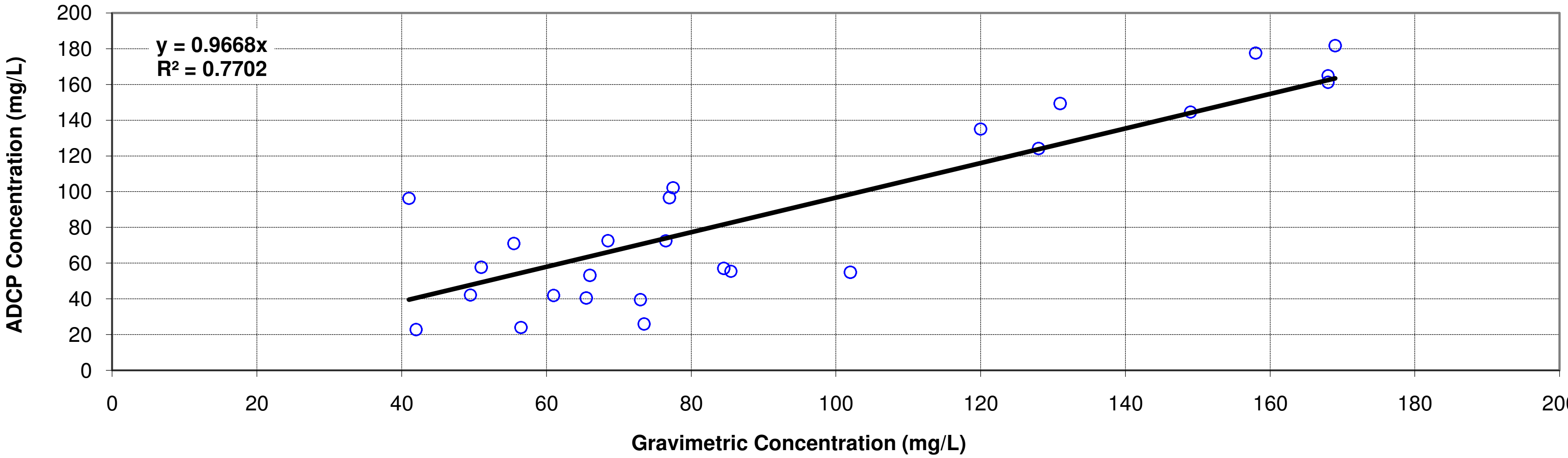


Figure	*USACE Harborwide TSS* *Far Field Survey* *KVK Cutterhead*	**Comparison of gravimetric and ADCP estimates of TSS concentration** **a) Concentration vs. Time b) ADCP Concentration vs. Gravimetric Concentration** **23 March 2011 TSS Survey**	Tide
8			Flood